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PRELIMINARY ASSESSMENT

DATE : June, 1990

PREPARED BY: Tom Morris, Environmental Specialist
Navajo Superfund Office

SITE : Navajo- Nanabah Vandever Uranium Mine

EPA ID# : Not Assigned

1. SITE INFORMATION

SITE LOCATION: The abandoned Nanabah Vandever Uranium mine is located approximately four miles east northeast of Prewitt, New Mexico 87045 (Fig 1, Ref 1). Travel east on U.S. 66 frontage road from the Prewitt Post Office for approximately one mile. Turn north on an improved dirt road and go under the railroad. Take the second left (4 mi.). Go through the gate (no trespassing sign). The site is 0.75 miles from the gate on the south side of Haystack Mountain. (Fig.8) The site map location is T13N, R11W, Section 24.222 Bluewater Quad, New Mexico (1). Geographic coordinates for the site are 35° 20' 47" N latitude and 107° 57' 00" W longitude (1).

The mine is located on an expired mining claim approximately 1/4 section or 160 acres in size (40). The site itself is reported to be an open pit approximately 6 acres in size and 15-20 feet deep (23,24,27). Three different windshield surveys were conducted in the area, but no pit was found. It is possible the pit was filled in with waste from its own or adjacent mining activities. The waste piles are readily accessible (Fig. 4,5). This site is in close proximity to the Brown Vandever Mine site and several other abandoned uranium mine sites located on State lands (Fig.2).

OWNER AND OPERATOR: The Nanabah site is on an Indian Land Allotment issued to Nanabah Vandever in 1926 (41). The allotment, under the authority of the Bureau of Indian Affairs (BIA), has been probated to 31 heirs. Further information involves interaction with the heirs and the BIA (2). Currently, there is no operator. Past operators are listed under Section 2. The mineral rights belong to the current allotment owners (50).

PURPOSE OF INVESTIGATION: The Nanabah Vandever Uranium Mine was reported to be a potentially contaminated waste site by the Navajo Superfund Office field reconnaissance team in 1990.

BACKGROUND OPERATING HISTORY

The primary lease holders for the site were: 1952-54 Glen Williams; 1955-56 Santa Fe Uranium; 1955 Federal Uranium Corp., Santa Fe Uranium; 1956-57 Federal Uranium Corp. (26).

NEW MEXICO

THE MAP IS SCALE 1:500,000
 THE MAP IS SCALE 1:500,000

HIGHWAY MARKERS

INTERSTATE (I) UNITED STATES (US) STATE (S) TEXAS (TX) FARM OR RANCH (FR)

ROAD CLASSIFICATIONS

CONTROLLED ACCESS HIGHWAYS
 (Interchanges)
 OTHER DIVIDED HIGHWAYS
 PRINCIPAL THROUGH HIGHWAYS
 OTHER THROUGH HIGHWAYS
 OTHER ROADS
 In unimproved areas, square holes before using any unimproved roads

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SPECIAL FEATURES

STATE PARKS
 RECREATION AREAS
 SELECTED BEST AREAS
 POINTS OF INTEREST
 BIR AREAS
 SCHEDULED AIRLINE STOPS
 MILITARY AIRPORTS
 TOURIST INFORMATION
 RELEASES

POPULATION SYMBOLS

● Less than 1,000
 ○ 1,000 to 2,500
 ● 2,500 to 5,000
 ○ 5,000 to 10,000
 ● 10,000 to 25,000
 ○ 25,000 to 50,000
 ● 50,000 and over

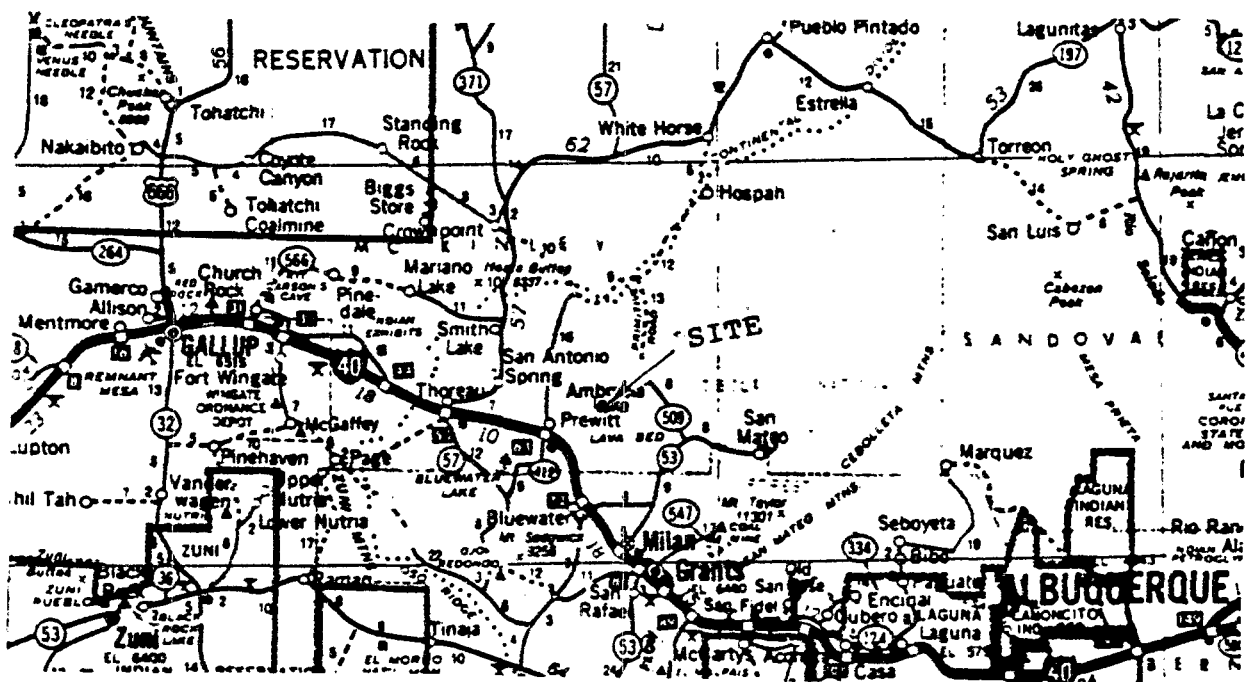


FIGURE # 1 ; REPRINTED BY PERMISSION

NAVAJO SUPERFUND OFFICE

NAVAJO-NANABAH VAN-
 DEVER URANIUM MINE

JUNE, '90 T. MORRIS

The site is in the Ambrosia Lake subdistrict of the Grants uranium district (25,27). No historical record of naturally occurring radiation levels for the area has survived to the present (47). As aforementioned, the site is recorded as being an open pit. It is presumed the mining operation was carried out using conventional mining techniques of drilling/blasting and front end loaders. Overburden and low-grade ore were dumped over the side of the outcrop onto the plain below (Figs.4,5).

The site produced 24,638 tons of ore containing 0.22% U_3O_8 (Uranium) and 0.18% VO_5 (Vanadium). The milled ore yield was 115,075 lbs U_3O_8 and 85,545 lbs. VO_5 (26,27). The ore was transported to the Anaconda Mill in Bluewater, NM during the mining period (49).

KNOWN/POTENTIAL PROBLEMS/CONTAMINATES

The waste piles are suspected of producing surface and groundwater leachate and fugitive dusts containing toxic heavy metals and radionuclides. These possibly migrate onto grazing lands, into homes, and into two aquifers of concern (Fig.4, Ref.6,42). Leachable heavy metals including: Selenium, Lead, Arsenic, Barium, Molybdenum, Uranium, and Vanadium were found in an area ore analysis, and therefore suspected to be in the waste piles (29,30,33,34). Other suspected contaminants related to the waste piles are the radioactive uranium progenies: Radon, Radium, Bismuth, Thorium, and Polonium (28,31,32). The toxicities of these heavy metals and radionuclides are well documented (35,36,37,38,39).

The site has no containment, barriers, or warning signs, and is readily accessible to humans and animals (Fig.4,5). The nearest residence is 1/4 mile southwest of the site (Fig.6,8). As aforementioned, livestock graze at the base of the waste piles. The access road produced scintillometer readings of 100 mR/hr compared to a background of 6 mR/hr and 2.5×10^4 CPM (11). The Navajo Superfund Office's Digilert (nuclear radiation monitor) set at 100 CPM sounded inside the closed reconnaissance vehicle near the site. There is no documentation of emergencies, accidents, or remedial actions related to the site.

3. WASTE CONTAINMENT/HAZARDOUS SUBSTANCE

The waste piles contain an estimated 208.52 tons of toxic compounds and elements dispersed throughout (8). There is no containment of these piles, and the potential for fugitive dust and leachate exists. The elements of major concern are: Uranium, Vanadium, Radium, Radon, Thorium, Bismuth, Polonium, Selenium, Lead, Arsenic, Barium, and Molybdenum (28,34).

4. PATHWAY CHARACTERISTICS

AIR PATHWAY: The potential migration for radon gas and fugitive dust containing toxic elements from the waste piles is high due to

the semi-arid nature of the area, the particulate nature of the waste, and the area's sporadic, southwesterly high winds.

GROUNDWATER PATHWAYS: Regionally, the site is bounded on the north by the Central San Juan Basin and on the south by the Zuni Uplift. The site is located on the Chaco Slope (43). The ore body was contained almost exclusively in the Jurassic, Todilto Limestone Outcrop (Fig.3 Ref.25,27,28). The Todilto is underlain by the Jurassic, Entrada Sandstone formation which contains the major of two aquifers of concern (3,22). The Entrada dips 4 degrees to the northeast in the direction of well #16T-521 (3,22). This formation is the aquifer source for well #16T-521 which is for stock water and possibly domestic use (16). It is also the artesian spring source 1/2 mile northwest from the site (Fig.8 Ref.1). The depth to water is 100 ft (22). The other aquifer for the site is the Upper Triassic, Sonsela Sandstone member of the Chinle formation which sources the tribal municipal well #16T-551 (12,16,22). The depth to water is 1000 ft. (16). The area is faulted with a hydraulic conductivity estimated to be 10^{-3} to 10^{-5} cm/sec (3,13). The analysis of well #16T-551 in 1989 showed it to be in compliance for heavy metals and radionuclides (9). No radionuclide/heavy metal analysis records were available for stock wells. The net average annual precipitation for the site is -43 inches (18,19,20).

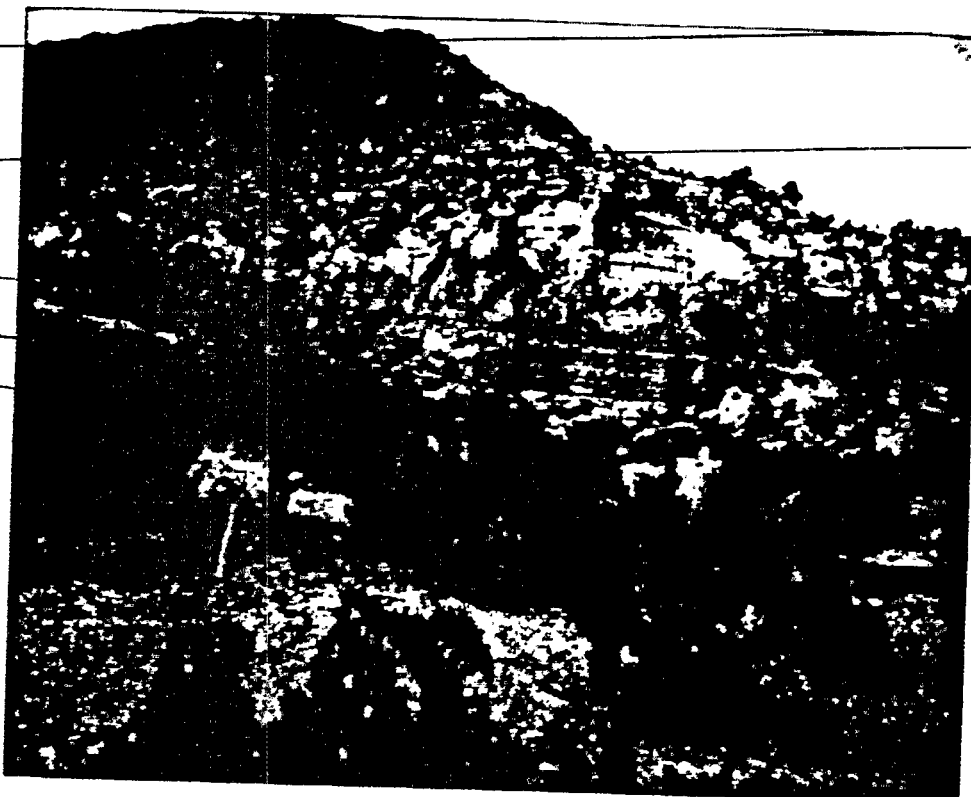
SURFACE WATER PATHWAYS: The site is located on an outcrop which is sloped 5 degrees to the north northeast (1). The waste piles set on the plain below the outcrop (Fig.4). The estimated upgradient drainage area is 23.7 acres (17). The drainage from the waste piles runs onto the plain following no visible channel, and appears to disperse over the plain (Fig.4). Therefore, there is no observable downstream drainage. The regional, 1-Yr, 24-hr. rainfall event for the site is 1.26 inches (45). A seasonal monsoon cloudburst is likely to carry leachate and particulates onto the plain.

ON SITE PATHWAY: The site has no barricades, containment, or warning signs. It is easily accessible by humans and animals. There are direct routes of ingestion and inhalation of particulates and Radon gas (45).

5. TARGETS

GROUNDWATER TARGETS: There are three active wells and one artesian spring within the 4 mile site radius (Fig.7 Ref.1,15,16). The Haystack Mountain community municipal water system and former stock well #16T-551 was developed by the Indian Health Service (IHS), and is currently operated by the tribe (12,16). The system serves approximately 500 people (1,5,12,14). The total population estimate for the area is 587 (1,5,12,14). It is assumed that people not connected to the water system may utilize it via family and/or friends. It is possible that approximately 85 area residents also utilize stock well #16T-521 or an artesian spring northwest of the site for domestic purposes (Fig.7,8). The stockwells and spring are related to the Entrada Sandstone formation which lies directly below the uranium-bearing Todilto Limestone, and is therefore

DAKOTA Kd	
MORRISON FORMATION	Jm
COW SPRINGS SS	Jcs
SUMMERVILLE Js	
TODILTO	Jt



20TH FE.
(GEOL.)

FIGURE 3

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE
LOCAL GEOLOGY: PATRICK
ANTONIO, NSO STAFF HYDROLO-
GIST TO P. MOLLOY

PCM

APRIL, '90

P. MOLLOY

NAVAO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE USEPA SITE NO. NOT ASSIGNED

DATE APRIL 11, 1990 TIME _____ WEATHER CLEAR

PHOTOGRAPHER P. MOLLOY ANGLE/DIRECTION 270° W

FILM TYPE POLAROID FRAME NO. 23

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ()

2. Surface Water Sample ()

3. Air Monitoring Device ()

Reading: _____

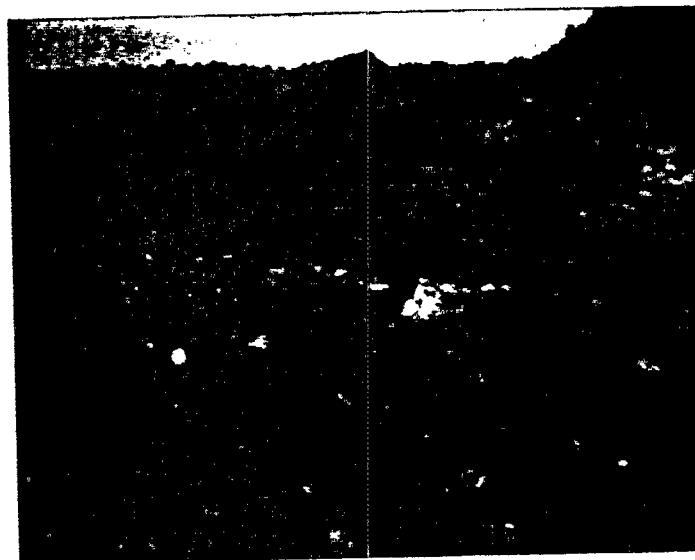
4. Radiation Survey (X)

Reading: _____

5. Deep Well Water Sample ()

6. Photograph Below: YES

FIGURE 5



23rd FR-T.P.
(N. VANDEVER?)
K
DRAW.

7. DESCRIPTION NANA - A - BAH VANDEVER MINE ? WESTERN
EXTENT OF B. VANDEVER WORKS, NOTE DRAINAGE, LOOK-
ING W

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED
DATE MAY 11, 1990 **TIME** 1:30pm **WEATHER** BROKEN CLOUDS, WINDY
PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 60°/NE
FILM TYPE POLAROID **FRAME NO.** 2

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ()
2. Surface Water Sample ()
3. Air Monitoring Device ()

Reading: _____

4. Radiation Survey (X)

Reading: LUDELUM#19 - RANGE: 11 - 22uR.hr⁻¹

5. Deep Well ^{ESP - IT} Water Sample RANGE: 1.1 - 2.5(10⁴)cpm

6. Photograph Below: DRAINAGE SW OF N. VANDEVER URANIUM MINE



FIGURE 4

FR. #2, LKG NE

7. **DESCRIPTION** MIGRATION OF RADIOACTIVE MATERIAL ACROSS ROAD UNCERTAIN DUE TO RADIOACTIVE MATERIAL DEPOSITED ON ROAD DURING HAULING OPERATIONS. NOTE SHEEP GRAZING IN FIELD, RIGHT CENTER MIDDLEGROUND.



FIGURE 6

RESIDENCE WITH GARDEN 1/4 MILE FROM SITE

*NOTE BACKGROUND WASTE PILE

NAVAJO SUPERFUND OFFICE

NANABAH VANDEVER
URANIUM MINE

JUNE '90 T. MORRIS



FIGURE 7

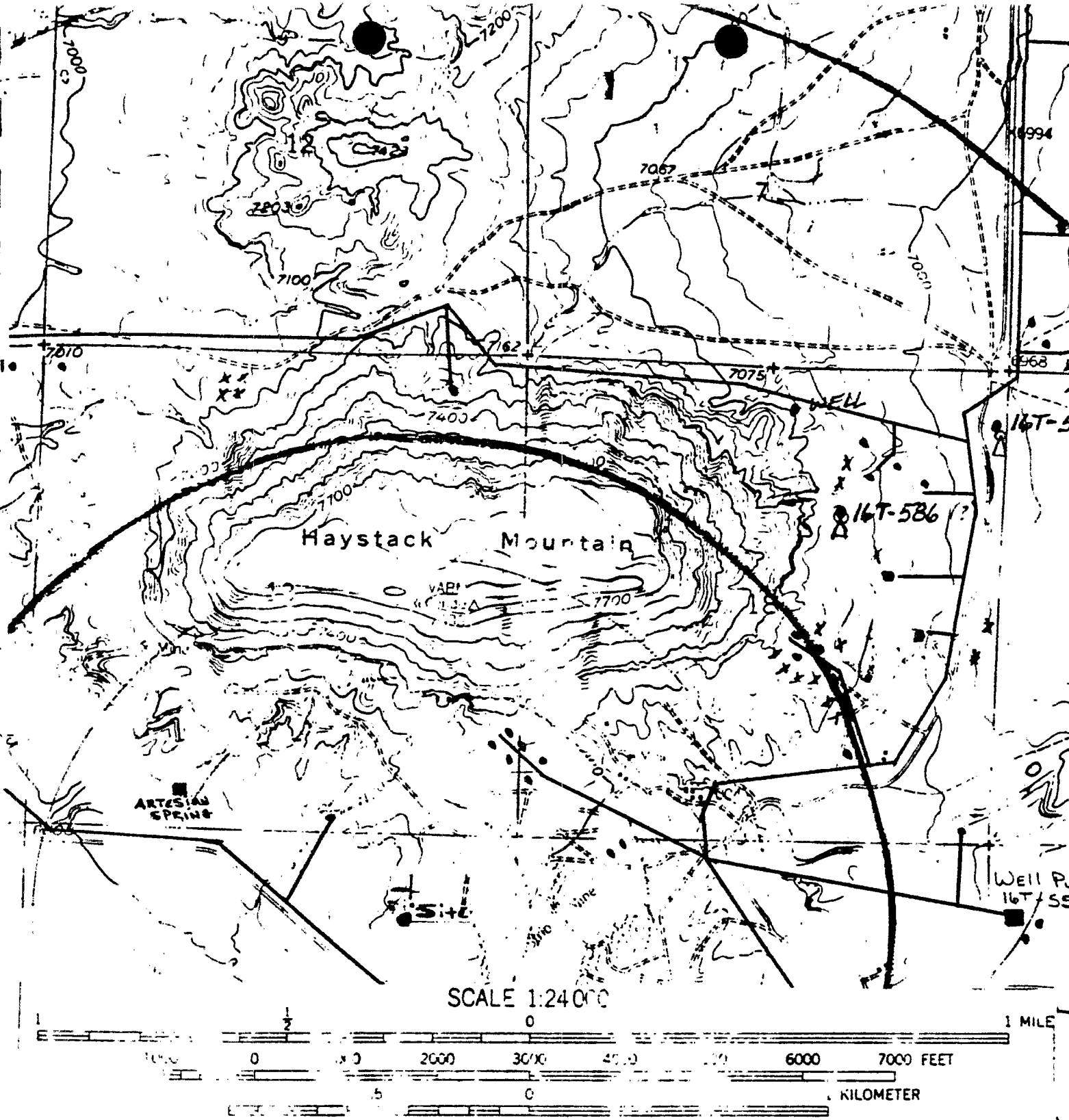
ARTESIAN SPRING 1/2 MILE FROM SITE

* Note Background Waste Pile

NAVAJO SUPERFUND OFFICE

NANABAH VANDEVER
URANIUM MINE

JUNE '90 T. MORRIS



SCALE 1:24 000
CONTOUR INTERVAL 20 FEET
ELEVATION IS MEAN SEA LEVEL

**NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE**

FIGURE 8

T. MORRIS JUNE '90

subject to leachate contamination of heavy metals and radionuclides.

SURFACE WATER TARGETS: There is no well defined drainage. Therefore, the primary targets would be the flora within the drainage area which could bioaccumulate contaminants to be ingested by grazing animals, and fauna which use any storm-related puddles as drinking water or wallows.

AIR TARGETS: The site waste piles are emitting Radon gas at an estimated 7.33 Curies/Yr (45). This far exceeds the 20 pico curie standard (46). It is estimated that 57 people live within 1/2 mile of the site; 52 of them downwind (1,5,12,14). The combined Radon emissions from this site and the adjacent abandoned mines pose an immediate danger to these people.

ONSITE TARGETS: None known. The possibility exists that the species listed under Sensitive Environments may be affected. Also livestock and people have unhindered access.

SENSITIVE ENVIRONMENTS: At least one federally designated sensitive environment lies within 1 mile of the site (21). Also, there are listed/potential-threatened/endangered fauna and flora species in the Haystack Mountain area (10). These are: Endangered Black Footed Ferret (Mustela nigripes), Burrowing Owl (Athene cunicularia), Mexican Free-tailed Bat (Tadarida brasiliensis), Mexican Spotted Owl (Strix occidentalis), Goshawk, Sharpshinned Hawk, and Rhizome Fleabane (Erigeron rhizomatus).

6. OTHER REGULATORY INVOLVEMENT

PERMITS : No permit was found for Nanabah Vandever mine site.

STATE AGENCIES: None (Ref.47)

OTHER FEDERAL PROGRAMS: None (50)

REMOVAL CONSIDERATIONS: None

7. CONCLUSIONS AND RECOMMENDATIONS

The Nanabah Vandever mine site is dangerous and threatening. Put into the perspective of combined effects with adjacent abandoned uranium mines, and a problem results that calls for immediate attention. It must be noted that there are numerous abandoned mines in the Haystack Mountain area many of which are not on tribal or allotment lands. There is evidence of human activity on the waste piles and possibly entering adits. Remedial action is warranted for those sites related to the Navajo Nation. Minimally, barricades and warnings should be placed around those sites unrelated to the Navajo Nation. Neither the Navajo nor New Mexico Abandoned Mine Lands Programs have addressed the problems related to the Haystack Mountain abandoned Uranium mines. Because these mines are in the "Checkerboard" area of tribal, state, and private lands, neither

agency wants to get involved. This has resulted in the area residents being subjected to prolonged exposures of toxic and carcinogenic elements.

Allotment owners, while not on tribal lands, receive services from the Navajo Nation through their local chapter. The requirement for these services is that they be registered voters with the Navajo Nation. Any services provided by the chapter such as water, electricity, housing, roads, etc. must first be approved by the Bureau of Indian Affairs local agent (50). This paragraph was deemed necessary to show the connection between allotment lands and the Navajo Nation.

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REFERENCE #2

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

REFERENCE #2

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

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4. Contact Report
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From: T. Morris, Environmental Spec., Navajo Superfund Office
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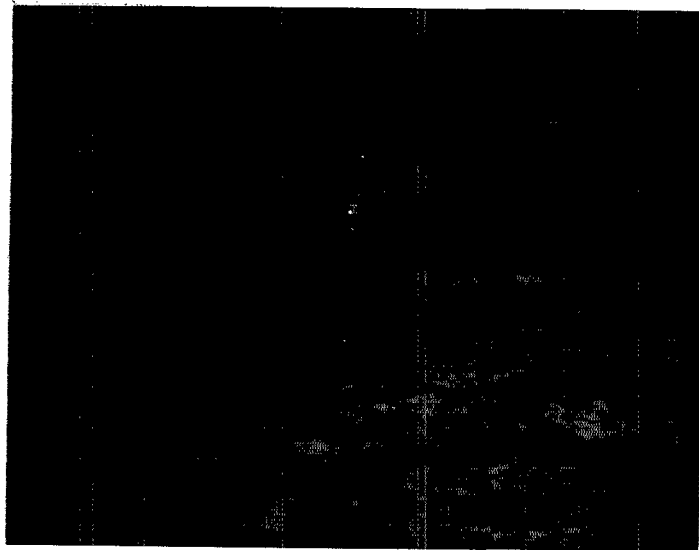


FIGURE 7

ARTESIAN SPRING 1/2 MILE FROM SITE

*Note Background Waste Pile

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URANIUM MINE

JUNE '90 T. MORRIS

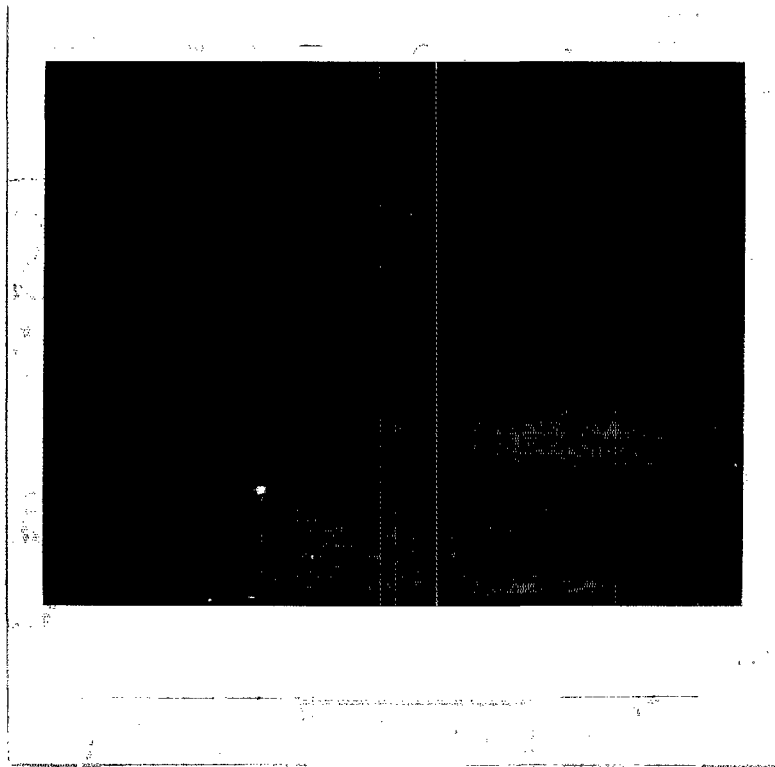


FIGURE 6

RESIDENCE WITH GARDEN 1/4 MILE FROM SITE

*Note Background Waste Pile

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URANIUM MINE

JUNE '90 T. MORRIS

agency wants to get involved. This has resulted in the area residents being subjected to prolonged exposures of toxic and carcinogenic elements.

Allotment owners, while not on tribal lands, receive services from the Navajo Nation through their local chapter. The requirement for these services is that they be registered voters with the Navajo Nation. Any services provided by the chapter such as water, electricity, housing, roads, etc. must first be approved by the Bureau of Indian Affairs local agent (50). This paragraph was deemed necessary to show the connection between allotment lands and the Navajo Nation.

subject to leachate contamination of heavy metals and radionuclides.

SURFACE WATER TARGETS: There is no well defined drainage. Therefore, the primary targets would be the flora within the drainage area which could bioaccumulate contaminants to be ingested by grazing animals, and fauna which use any storm-related puddles as drinking water or wallows.

AIR TARGETS: The site waste piles are emitting Radon gas at an estimated 7.33 Curies/Yr (45). This far exceeds the 20 pico curie standard (46). It is estimated that 57 people live within 1/2 mile of the site; 52 of them downwind (1,5,12,14). The combined Radon emissions from this site and the adjacent abandoned mines pose an immediate danger to these people.

ONSITE TARGETS: None known. The possibility exists that the species listed under Sensitive Environments may be affected. Also livestock and people have unhindered access.

SENSITIVE ENVIRONMENTS: At least one federally designated sensitive environment lies within 1 mile of the site (21). Also, there are listed/potential-threatened/endangered fauna and flora species in the Haystack Mountain area (10). These are: Endangered Black Footed Ferret (Mustela nigripes), Burrowing Owl (Athene cunicularia), Mexican Free-tailed Bat (Tadarida brasiliensis), Mexican Spotted Owl (Strix occidentalis), Goshawk, Sharpshinned Hawk, and Rhizome Fleabane (Erigeron rhizomatus).

6. OTHER REGULATORY INVOLVEMENT

PERMITS : No permit was found for Nanabah Vandever mine site.

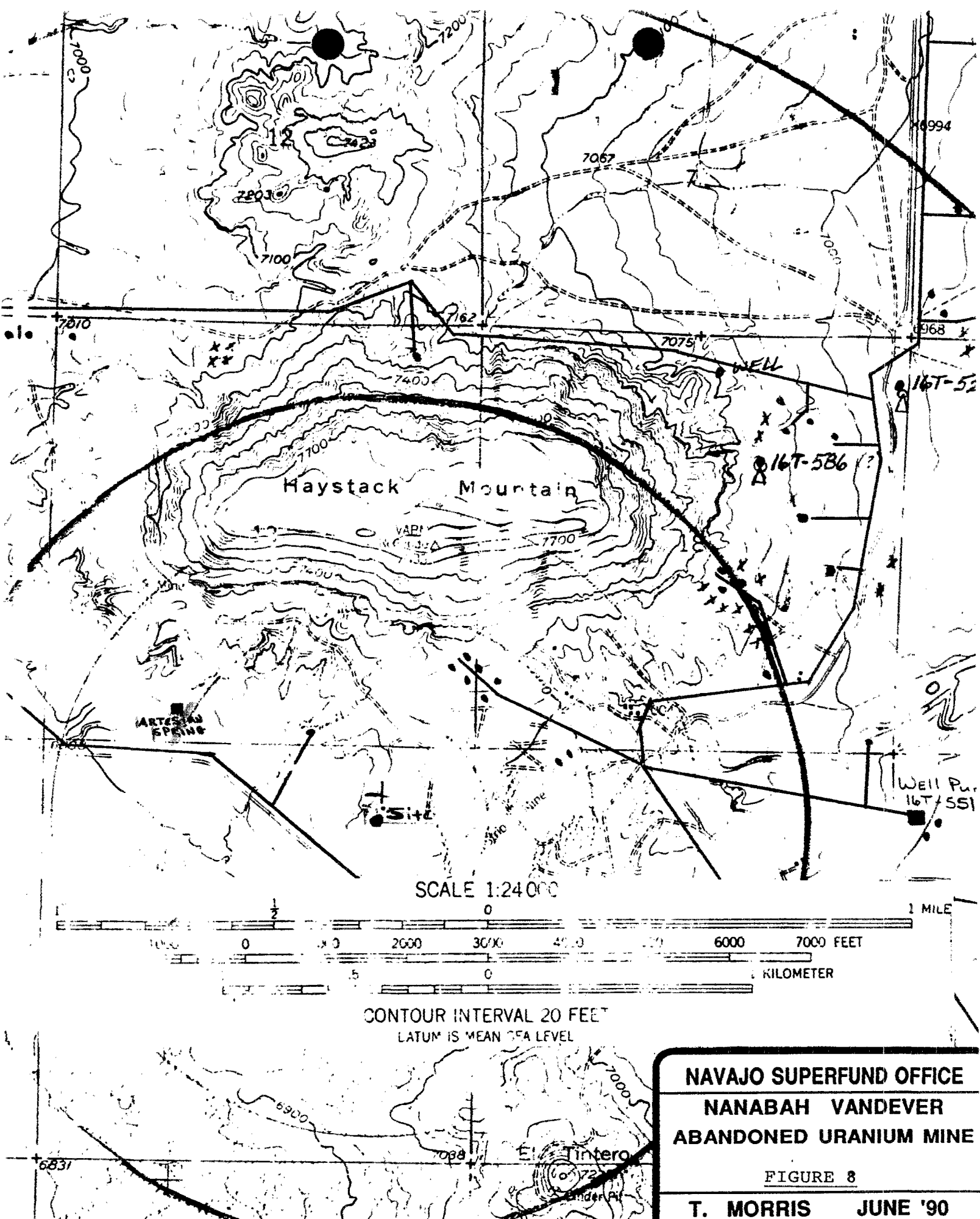
STATE AGENCIES: None (Ref.47)

OTHER FEDERAL PROGRAMS: None (50)

REMOVAL CONSIDERATIONS: None

7. CONCLUSIONS AND RECOMMENDATIONS

The Nanabah Vandever mine site is dangerous and threatening. Put into the perspective of combined effects with adjacent abandoned uranium mines, and a problem results that calls for immediate attention. It must be noted that there are numerous abandoned mines in the Haystack Mountain area many of which are not on tribal or allotment lands. There is evidence of human activity on the waste piles and possibly entering adits. Remedial action is warranted for those sites related to the Navajo Nation. Minimally, barricades and warnings should be placed around those sites unrelated to the Navajo Nation. Neither the Navajo nor New Mexico Abandoned Mine Lands Programs have addressed the problems related to the Haystack Mountain abandoned Uranium mines. Because these mines are in the "Checkerboard" area of tribal, state, and private lands, neither



NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE USEPA SITE NO. NOT ASSIGNED

DATE APRIL 11, 1990 TIME _____ WEATHER CLEAR

PHOTOGRAPHER P. MOLLOY ANGLE/DIRECTION 270°/W

FILM TYPE POLAROID FRAME NO. 23

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ()

2. Surface Water Sample ()

3. Air Monitoring Device ()

Reading: _____

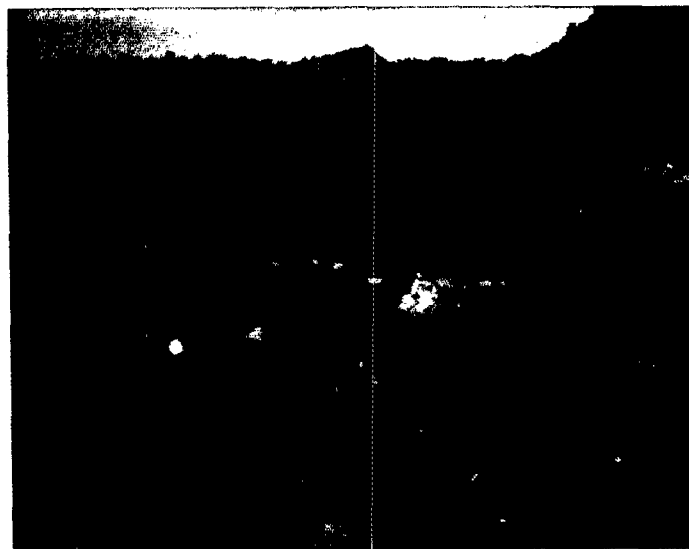
4. Radiation Survey (X)

Reading: _____

5. Deep Well Water Sample ()

6. Photograph Below: YES

FIGURE 5



23nd FR - T.P.
(N. VANDEVER?)

FRAN

7. DESCRIPTION NANA - A - BAH VANDEVER MINE ? WESTERN
EXTENT OF B. VANDEVER WORKS, NOTE DRAINAGE, LOOK-
ING W

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED
DATE MAY 11, 1990 **TIME** 1:30pm **WEATHER** BROKEN CLOUDS, WINDY
PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 60°/NE
FILM TYPE POLAROID **FRAME NO.** 2

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ()
2. Surface Water Sample ()
3. Air Monitoring Device ()

Reading: _____

4. Radiation Survey (X)

Reading: LUDDLUM#19 - RANGE: 11 - 22uR.hr⁻¹

5. Deep Well Water Sample ^{ESP - IT - RANGE: 1.1 - 2.5(10⁴)cpm} ()

6. Photograph Below: DRAINAGE SW OF N. VANDEVER URANIUM MINE



FIGURE 4

FR. #2, LKG NE

7. **DESCRIPTION** MIGRATION OF RADIOACTIVE MATERIAL ACROSS ROAD UNCERTAIN DUE TO RADIOACTIVE MATERIAL DEPOSITED ON ROAD DURING HAULING OPERATIONS. NOTE SHEEP GRAZING IN FIELD, RIGHT CENTER MIDDLEGROUND.

DAKOTA Kd	
MORRISON FORMATION	
Jm	
COW SPRINGS	
SS Jcs	
SUMMERVILLE Js	
TODILTO Jt	



20TH FR.
(GEOL.)

FIGURE 3

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE
LOCAL GEOLOGY: PATRICK
ANTONIO, NSO STAFF HYDROLO-
GIST TO P. MOLLOY

PCM

APRIL, '90

P. MOLLOY

the semi-arid nature of the area, the particulate nature of the waste, and the area's sporadic, southwesterly high winds.

GROUNDWATER PATHWAYS: Regionally, the site is bounded on the north by the Central San Juan Basin and on the south by the Zuni Uplift. The site is located on the Chaco Slope (43). The ore body was contained almost exclusively in the Jurassic, Todilto Limestone Outcrop (Fig.3 Ref.25,27,28). The Todilto is underlain by the Jurassic, Entrada Sandstone formation which contains the major of two aquifers of concern (3,22). The Entrada dips 4 degrees to the northeast in the direction of well #16T-521 (3,22). This formation is the aquifer source for well #16T-521 which is for stock water and possibly domestic use (16). It is also the artesian spring source 1/2 mile northwest from the site (Fig.8 Ref.1). The depth to water is 100 ft (22). The other aquifer for the site is the Upper Triassic, Sonsela Sandstone member of the Chinle formation which sources the tribal municipal well #16T-551 (12,16,22). The depth to water is 1000 ft. (16). The area is faulted with a hydraulic conductivity estimated to be 10^{-3} to 10^{-5} cm/sec (3,13). The analysis of well #16T-551 in 1989 showed it to be in compliance for heavy metals and radionuclides (9). No radionuclide/heavy metal analysis records were available for stock wells. The net average annual precipitation for the site is -43 inches (18,19,20).

SURFACE WATER PATHWAYS: The site is located on an outcrop which is sloped 5 degrees to the north northeast (1). The waste piles set on the plain below the outcrop (Fig.4). The estimated upgradient drainage area is 23.7 acres (17). The drainage from the waste piles runs onto the plain following no visible channel, and appears to disperse over the plain (Fig.4). Therefore, there is no observable downstream drainage. The regional, 1-Yr, 24-hr. rainfall event for the site is 1.26 inches (45). A seasonal monsoon cloudburst is likely to carry leachate and particulates onto the plain.

ON SITE PATHWAY: The site has no barricades, containment, or warning signs. It is easily accessible by humans and animals. There are direct routes of ingestion and inhalation of particulates and Radon gas (45).

5. TARGETS

GROUNDWATER TARGETS: There are three active wells and one artesian spring within the 4 mile site radius (Fig.7 Ref.1,15,16). The Haystack Mountain community municipal water system and former stock well #16T-551 was developed by the Indian Health Service (IHS), and is currently operated by the tribe (12,16). The system serves approximately 500 people (1,5,12,14). The total population estimate for the area is 587 (1,5,12,14). It is assumed that people not connected to the water system may utilize it via family and/or friends. It is possible that approximately 85 area residents also utilize stock well #16T-521 or an artesian spring northwest of the site for domestic purposes (Fig.7,8). The stockwells and spring are related to the Entrada Sandstone formation which lies directly below the uranium-bearing Todilto Limestone, and is therefore

The site is in the Ambrosia Lake subdistrict of the Grants uranium district (25,27). No historical record of naturally occurring radiation levels for the area has survived to the present (47). As aforementioned, the site is recorded as being an open pit. It is presumed the mining operation was carried out using conventional mining techniques of drilling/blasting and front end loaders. Overburden and low-grade ore were dumped over the side of the outcrop onto the plain below (Figs.4,5).

The site produced 24,638 tons of ore containing 0.22% U_3O_8 (Uranium) and 0.18% V_2O_5 (Vanadium). The milled ore yield was 115,075 lbs U_3O_8 and 85,545 lbs. V_2O_5 (26,27). The ore was transported to the Anaconda Mill in Bluewater, NM during the mining period (49).

KNOWN/POTENTIAL PROBLEMS/CONTAMINATES

The waste piles are suspected of producing surface and groundwater leachate and fugitive dusts containing toxic heavy metals and radionuclides. These possibly migrate onto grazing lands, into homes, and into two aquifers of concern (Fig.4, Ref.6,42). Leachable heavy metals including: Selenium, Lead, Arsenic, Barium, Molybdenum, Uranium, and Vanadium were found in an area ore analysis, and therefore suspected to be in the waste piles (29,30,33,34). Other suspected contaminants related to the waste piles are the radioactive uranium progenies: Radon, Radium, Bismuth, Thorium, and Polonium (28,31,32). The toxicities of these heavy metals and radionuclides are well documented (35,36,37,38,39).

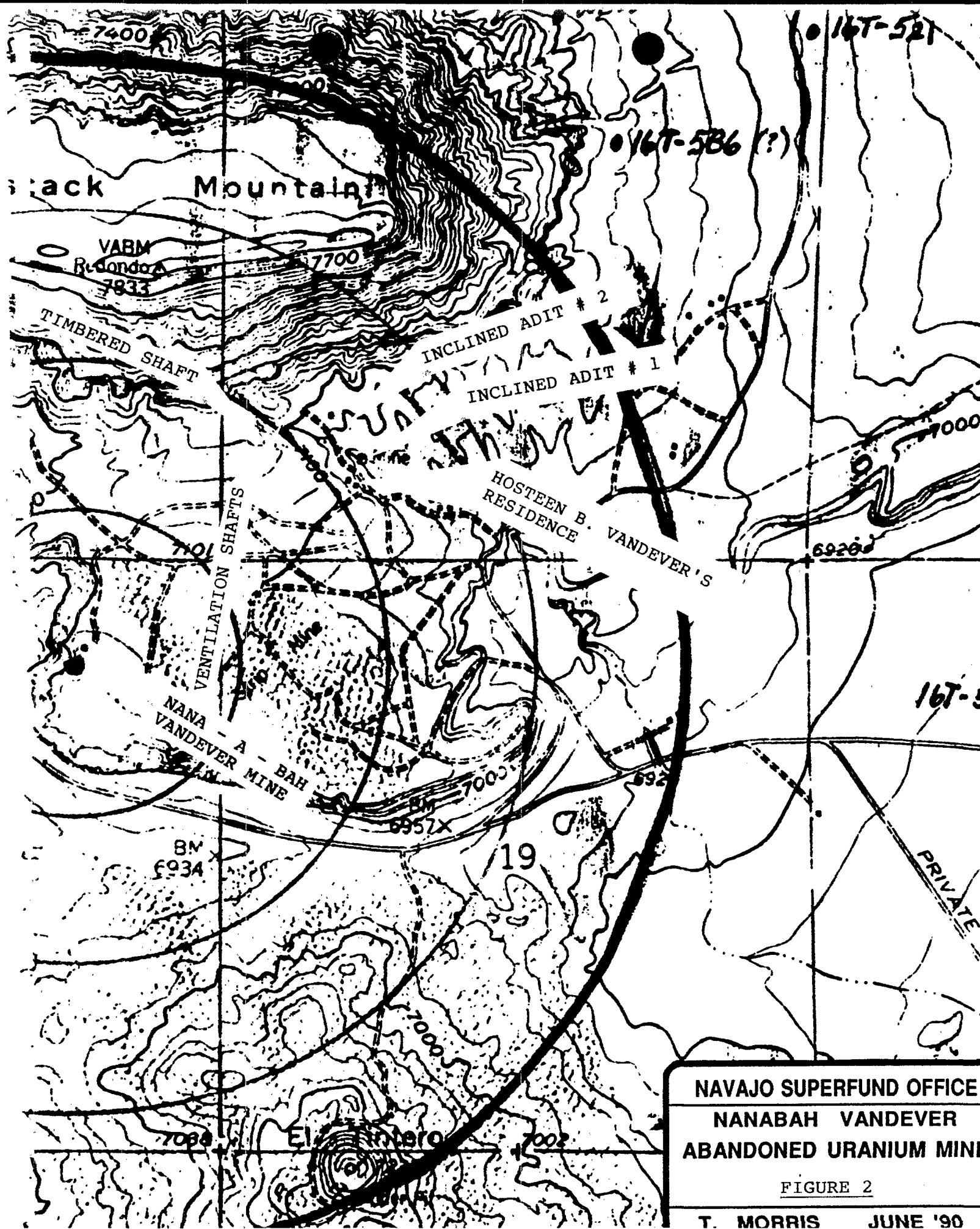
The site has no containment, barriers, or warning signs, and is readily accessible to humans and animals (Fig.4,5). The nearest residence is 1/4 mile southwest of the site (Fig.6,8). As aforementioned, livestock graze at the base of the waste piles. The access road produced scintillometer readings of 100 mR/hr compared to a background of 6 mR/hr and 2.5×10^4 CPM (11). The Navajo Superfund Office's Digilert (nuclear radiation monitor) set at 100 CPM sounded inside the closed reconnaissance vehicle near the site. There is no documentation of emergencies, accidents, or remedial actions related to the site.

3. WASTE CONTAINMENT/HAZARDOUS SUBSTANCE

The waste piles contain an estimated 208.52 tons of toxic compounds and elements dispersed throughout (8). There is no containment of these piles, and the potential for fugitive dust and leachate exists. The elements of major concern are: Uranium, Vanadium, Radium, Radon, Thorium, Bismuth, Polonium, Selenium, Lead, Arsenic, Barium, and Molybdenum (28,34).

4. PATHWAY CHARACTERISTICS

AIR PATHWAY: The potential migration for radon gas and fugitive dust containing toxic elements from the waste piles is high due to



NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

FIGURE 2

T. MORRIS JUNE '90

NEW MEXICO

THE MAP IS MADE
FOR THE U.S. GOVERNMENT

HIGHWAY MARKERS

INTERSTATE (55) UNITED STATES (26) STATE (59) TEXAS (158) FARM OR RANCH

ROAD CLASSIFICATIONS

CONTROLLED ACCESS HIGHWAYS (Interchange numbers are indicated)
OTHER DIVIDED HIGHWAYS
PRINCIPAL THROUGH HIGHWAYS
OTHER THROUGH HIGHWAYS
OTHER ROADS
In unfamiliar areas require locally before using any unmarked roads

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SPECIAL FEATURES

STATE PARKS
RECREATION AREAS
SELECTED BEST AREAS
POINTS OF INTEREST
SCHEDULED AIRLINE STOPS
MILITARY AIRPORTS
TOURIST INFORMATION
MILEAGE

POPULATION SYMBOLS

State Capital
Under 1,000
1,000 to 2,500
2,500 to 5,000
5,000 to 10,000
10,000 to 25,000
25,000 to 50,000
50,000 to 100,000
100,000 and over

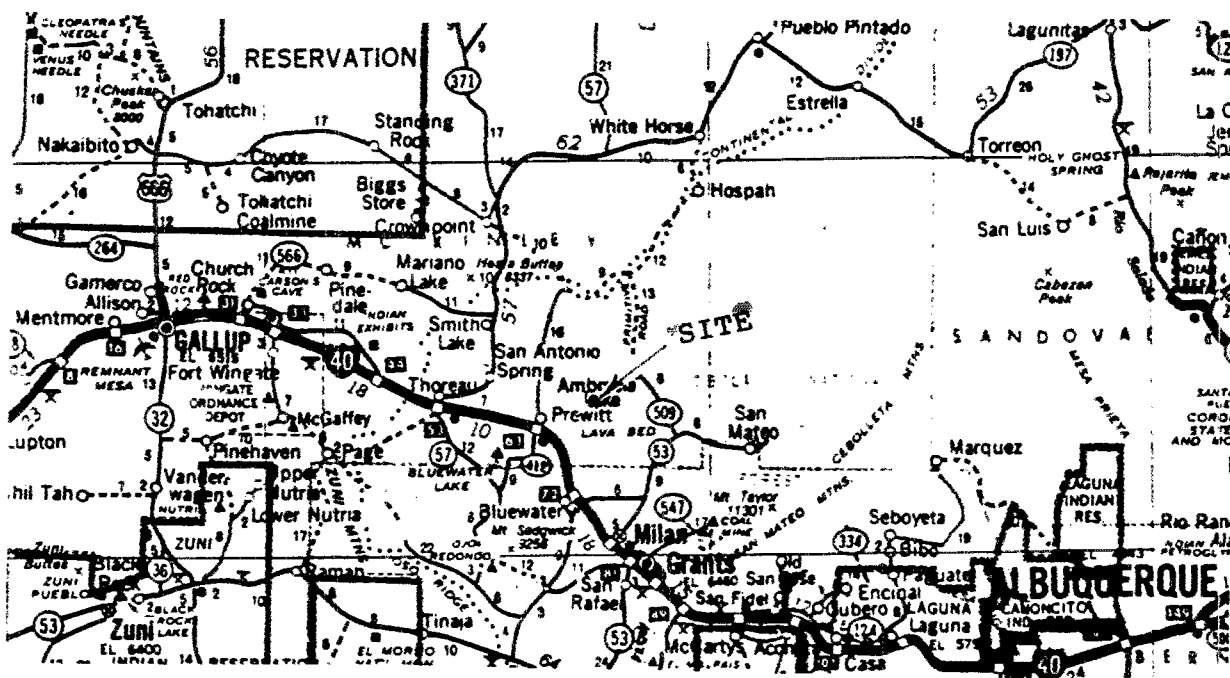


FIGURE # 1 ; REPRINTED BY PERMISSION

NAVAJO SUPERFUND OFFICE

NAVAJO-NANABAH VAN-
DEVER URANIUM MINE

JUNE, '90 T. MORRIS

PRELIMINARY ASSESSMENT

DATE : June, 1990

PREPARED BY: Tom Morris, Environmental Specialist
Navajo Superfund Office

SITE : Navajo- Nanabah Vandever Uranium Mine

EPA ID# : Not Assigned NMD986669109

1. SITE INFORMATION

SITE LOCATION: The abandoned Nanabah Vandever Uranium mine is located approximately four miles east northeast of Prewitt, New Mexico 87045 (Fig 1, Ref 1). Travel east on U.S. 66 frontage road from the Prewitt Post Office for approximately one mile. Turn north on an improved dirt road and go under the railroad. Take the second left (4 mi.). Go through the gate (no trespassing sign). The site is 0.75 miles from the gate on the south side of Haystack Mountain. (Fig. 8) The site map location is T13N, R11W, Section 24.222 Bluewater Quad, New Mexico (1). Geographic coordinates for the site are 35° 20' 47" N latitude and 107° 57' 00" W longitude (1)..

The mine is located on an expired mining claim approximately 1/4 section or 160 acres in size (40). The site itself is reported to be an open pit approximately 6 acres in size and 15-20 feet deep (23,24,27). Three different windshield surveys were conducted in the area, but no pit was found. It is possible the pit was filled in with waste from its own or adjacent mining activities. The waste piles are readily accessible (Fig. 4,5). This site is in close proximity to the Brown Vandever Mine site and several other abandoned uranium mine sites located on State lands (Fig.2).

OWNER AND OPERATOR: The Nanabah site is on an Indian Land Allotment issued to Nanabah Vandever in 1926 (41). The allotment, under the authority of the Bureau of Indian Affairs (BIA), has been probated to 31 heirs. Further information involves interaction with the heirs and the BIA (2). Currently, there is no operator. Past operators are listed under Section 2. The mineral rights belong to the current allotment owners (50).

PURPOSE OF INVESTIGATION: The Nanabah Vandever Uranium Mine was reported to be a potentially contaminated waste site by the Navajo Superfund Office field reconnaissance team in 1990.

BACKGROUND OPERATING HISTORY

The primary lease holders for the site were: 1952-54 Glen Williams; 1955-56 Santa Fe Uranium; 1955 Federal Uranium Corp., Santa Fe Uranium; 1956-57 Federal Uranium Corp. (26).

WASTE CONTAINMENT AND HAZARDOUS SUBSTANCE IDENTIFICATION

SOURCE TYPE	SIZE (Volume/Area)	ESTIMATED WASTE QUANTITY	SPECIFIC COMPOUNDS	CONTAINMENT ²	SOURCE OF INFORMATION
MINE WASTE PILES					
A	36,814.8 yd ³	160.4 Tons	U ₃ O ₈ , V ₂ O ₅	NONE	Ref.8,25,26,27, 34
B	12,148.9 yd ³	48.1 Tons	U ₃ O ₈ , V ₂ O ₅		Fig.4,5
OPEN PIT	30,976 yd ²	UNKNOWN	U ₃ O ₈ , V ₂ O ₅	NONE	Ref.24,26,27,34 Fig.4,5
HEAVY METALS & METALLOIDS	UNKNOWN	UNKNOWN	SELENIUM LEAD ARSENIC BARIUM MOLYBDENUM	NONE	Ref.28,34 Fig.4,5
RADIOACTIVE PROGENIES	NONE	UNKNOWN	THORIUM RADON RADIUM BISMUTH POLONIUM	NONE	Ref.28,34 Fig.4,5

1 Use additional sheets if necessary

2 Evaluate containment of each source from the perspective of each migration pathway (e.g., ground water pathway - nonexistent, natural or synthetic liner, corroding underground storage tank; surface water - inadequate freeboard, corroding bulk tanks; air - unstabilized slag piles, leaking drums, etc).

TABLE 2
HYDROGEOLOGIC INFORMATION¹

STRATA NAME/DESCRIPTION	THICKNESS (ft.)	DEPTH TO WATER (ft.)	HYDRAULIC CONDUCTIVITY (cm/sec)	TYPE OF DISCONTINUITY ²	SOURCE OF INFORMATION
ENTRADA SANDSTONE Alternating fine-grained cross-bedded sandstone and calcareous siltstone	180-190	100	10^{-3} - 10^{-5}		Ref.13,16,22
WINGATE SANDSTONE Moderate brown to moderate reddish-orange medium grained crossbedded sandstone	120	NO AQUIFER	10^{-5} - 10^{-7}	UNCONFORMITY	Ref.13,16,22
CHINLE FORMATION Alternating layers of siltstone and sandstone	1395	1000	10^{-3} - 10^{-5}		Ref.13,16,22
MOENKOPI FORMATION Sandstone interbedded with lenticular pebble conglomerate and layers of limestone and sandstone	26	NO AQUIFER	10^{-5} - 10^{-7}	UNCONFORMITY	Ref.13,16,
SAN ANDRES LIMESTONE Interbedded and adjacent layers of limestone and sandstone	115	1500	10^{-3} - 10^{-5}	UNCONFORMITY	Ref.13,16,22

1 Use additional sheets if necessary

2 Identify the type of discontinuity within four-miles from the site (e.g., river, strata "pinches out", etc.)

34. CHECK FOR ANY FEDERAL VIOLATIONS:

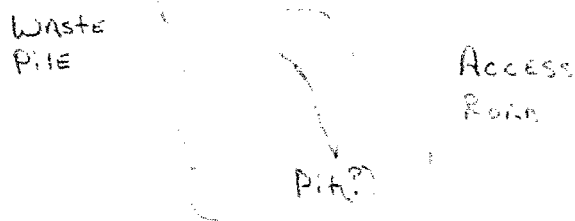
Rate : No data available

Federal: No data available

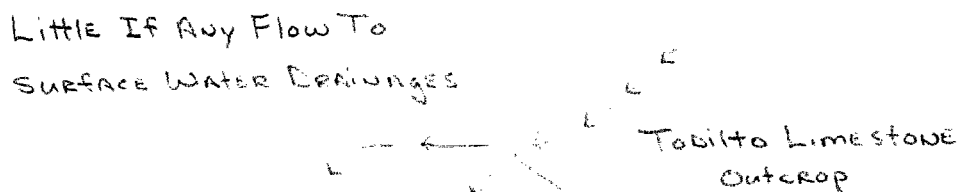
other

Source of information: REF. 40, 42

Include all pertinent features, e.g., wells, storage areas, underground storage tanks, waste areas, buildings, access roads, areas of ponded water, etc. Attach additional sheets with sketches of enlarged areas, if necessary.



Provide a simplified sketch of surface runoff and surface water flow system for 15 downstream miles. Include all pertinent features, e.g., intakes, recreation areas, fisheries, gauging stations, etc.



Waste
Pile

>5 - 10	_____
>10 - 20	_____
>20 - 40	_____
>40 - 60	_____
>60 - 80	_____
>80 - 100	_____
>100 - 125	_____

32. DETERMINE THE DISTANCE FROM THE SITE TO THE NEAREST OF EACH OF THE FOLLOWING LAND USES.

<u>Description</u>	<u>Distance</u> (miles)
Commercial/Industrial/ Institutional	5.24
Single Family Residential	0.25
Multi-Family Residential	0.5
Park	6.5
Agricultural	0.25

Source of information: Ref.1,5,12

33. SUMMARIZE THE POPULATION WITHIN A FOUR-MILE RADIUS OF THE SITE:

<u>DISTANCE</u> (miles)	<u>POPULATION</u>
Onsite	0
>0 - 1/4	5
>1/4 - 1/2	52
>1/2 - 1	47
>1 - 2	247
>2 - 3	189
>3 - 4	47

Source of information: Ref.1,5,12,14

ON THE TABLE BELOW:

<u>Distance</u> (miles)	<u>Population</u>
>0 - 1/4	5
>1/4 - 1/2	52
>1/2 - 1	47
>1 - 2	229
>2 - 3	158
>3 - 4	47

Source of information: Ref. 5, 12

29. IDENTIFY AND LOCATE (see Item # 26) POPULATION SERVED BY SURFACE WATER INTAKES WITHIN 15 DOWN-STREAM MILES OF THE SITE: None

Source of information: Ref. 1

30. DESCRIBE AND LOCATE FISHERIES WITHIN 15 DOWN-STREAM MILES OF THE SITE (i.e., provide standing crop or production and acreage, etc.): None

Source of information: Ref. 1

31. IF SURFACE WATER RECREATION AREAS EXIST, CHOOSE RECREATIONAL USE CATEGORY, AND THEN DETERMINE THE POPULATION WITHIN THE ASSIGNED RADIUS FROM THE RECREATION AREA. (Use GEMS to allocate into distance rings).

- a. Capital use and access improvements
NA (assigned radius = 125 miles)
- b. Access improvements only _____
(assigned radius = 80 miles)
- c. Observed use only _____ (assigned
radius = 40 miles)
- d. None of the above apply and access is
not restricted _____ (assigned
radius = 10 miles)

<u>Distance</u> (miles)	<u>Population</u>
>0 - 5	NA

18. DISCUSS THE PROBABLE SURFACE RUNOFF PATTERNS FROM THE SITE TO SURFACE WATERS:

The runoff fans out of an alluvial plain with no visible channel. (Fig.4; Ref.1)

19. PROVIDE A SIMPLIFIED SKETCH OF SURFACE RUNOFF AND SURFACE WATER FLOW SYSTEM FOR 15 DOWNSTREAM MILES (see Item # 36).

20. ANY POSITIVE OR CIRCUMSTANTIAL EVIDENCE OF SURFACE WATER CONTAMINATION? No

Describe: _____

21. ESTIMATE THE SIZE OF THE UPGRADIENT DRAINAGE AREA FROM THE SITE: 23.7 acres

22. DETERMINE THE AVERAGE ANNUAL STREAM FLOW OF DOWNSTREAM SURFACE WATERS.

Water body: None Flow: _____ cfs

Water body: _____ Flow: _____ cfs

Water body: _____ Flow: _____ cfs

Source of information: Windshield Survey

23. IS THE SITE OR PORTIONS THEREOF LOCATED IN SURFACE WATER? No (Ref.21)

24. IS THE SITE LOCATED IN A FLOODPLAIN (indicate flood frequency)? No (Ref.1,7)

25. IDENTIFY AND LOCATE (see Item # 36) ANY SURFACE WATER RECREATION AREA WITHIN 15 MILES DOWNSTREAM MILES OF THE SITE: None

Source of information: Ref.1

26. TWO YEAR 24-HOUR RAINFALL: 1.2 inches (Ref.19)

TARGETS

27. DISCUSS GROUND WATER USAGE WITHIN FOUR MILES OF THE SITE: Ground water is used for livestock watering and for domestic use.

Source of information: Ref.15,16

28. SUMMARIZE THE POPULATION SERVED BY GROUND WATER

WASTE CONTAINMENT/HAZARDOUS SUBSTANCE IDENTIFICATION

11. FOR EACH SOURCE AT THE SITE, SUMMARIZE ON TABLE 1 (page 12): 1) Methods of hazardous substance disposal, storage or handling; 2) size/volume/area of all features/structures that might contain hazardous waste; 3) condition/integrity of each storage/disposal feature or structure; and 4) types of hazardous substances handled.

12. BRIEFLY EXPLAIN HOW WASTE QUANTITY WAS ESTIMATED (e.g., historical records or manifests, permit applications, air photo measurements, etc.). Waste quantities were estimated by use of topographical map and waste pile photos.

Source of information: Ref.1,8

13. DESCRIBE ANY RESTRICTIONS OR BARRIERS ON ACCESSIBILITY TO ONSITE WASTE MATERIALS:

None

Source of information: Fig.4,5

GROUND WATER CHARACTERISTICS

14. ANY POSITIVE OR CIRCUMSTANTIAL EVIDENCE OF A RELEASE TO GROUND WATER? Yes

Describe: Nature of the contaminants and faulting being a possible pathway.

Source of information: Ref.3,29,30,31,32,33

15. ON TABLE 2 (page 13), GIVE NAMES, DESCRIPTIONS, AND CHARACTERISTICS OF GEOLOGICAL/HYDROGEOLOGIC UNITS UNDERLYING THE SITE.

16. NET PRECIPITATION: -43 inches (Ref.16,20)

SURFACE WATER CHARACTERISTICS

17. ARE THERE SURFACE WATER BODIES WITHIN 2 MILES OF THE SITE? Yes

X Ditches ___ Lakes X Pond

___ Creeks ___ Rivers X Other: washes

☒ Federal _____ County _____
☒ Other (describe): Indian Allotment

5. NAME OF SITE OPERATOR: Abandoned

ADDRESS: Unknown

CITY: _____ COUNTY: _____

STATE: _____ ZIP: _____

PHONE: _____

BACKGROUND/OPERATING HISTORY

6. DESCRIBE OPERATING HISTORY OF SITE: The mine was operated: 1952-54 Glen Williams; 1955-56 Santa Fe Uranium; 1955 Federal Uranium Corp. & Santa Fe Uranium; 1956-57 Federal Uranium Corp.

Source of information: Ref.26

7. DESCRIBE SITE AND NATURE OF SITE OPERATIONS (property size, manufacturing, waste disposal, storage, etc.): The lease is 1/4 section. The pit? is approximately 6 acres. The waste was dumped over the side of the outcrop onto the plain below. Manufacturing took place at the Anaconda Mill, Bluewater, NM.

Source of information: Fig.4,5; Ref.24,48

8. DESCRIBE ANY EMERGENCY OR REMEDIAL ACTIONS THAT HAVE OCCURRED AT THE SITE: No evidence of emergency or remedial actions.

Source of information: Fig.4,5

9. ARE THERE RECORDS OR KNOWLEDGE OF ACCIDENTS OR SPILLS INVOLVING SITE WASTES? No

Source of information: None known

10. DISCUSS EXISTING SAMPLING DATA AND BRIEFLY SUMMARIZE DATA QUALITY (e.g., sample objective, age/comparability, analytical methods, detection limits and QA/QC): No sampling records known to exist.

Source of Information: None Known

Descriptor: No people on the site. (Unpublished
Survey)

SITE INFORMATION

1. SITE NAME: Nanabah Vandever uranium mine
ADDRESS: TULSA, R11W, S11N Bladewater Quad
CITY: Prewitt COUNTY: McKinley
STATE: New Mexico ZIP: 87045
EPA ID: None
LATITUDE: 35°00'47" LONGITUDE: 107°57'00"

2. DIRECTIONS TO SITE (from nearest public road):

East from Prewitt, NM post office on frontage
road for one mile. Turn north on improved dirt
road under railroad overpass. Take second left
(4mi.) Site is 0.75mi. from the gate.

3. SITE OWNERSHIP HISTORY (for additional owners,
if necessary):

A. Name of current owner: Nanabah Vandever
Helms
Address: Contact: RIA Rosley (Cavey Morris)
City: Crownpoint County: McKinley
State: New Mexico Zip: 87315
Dates: From: To: Phone: 505-786-6116

B. Name of previous owner: Nanabah Vandever
Address: Deceased
City: _____ County: _____
State: _____ Zip: _____
Dates: From: _____ To: _____ Phone: _____

For past ownership data, RIA Rosley
Crownpoint, NM 87315 (Ref. 2)

4. TYPE OF OWNERSHIP (Check all that apply):

☐ Private ☐ State ☐ Tribal

PA QUESTIONNAIRE

Name: Tom Morris

Location: T12N, R11W, S. 24

Site Name: Nanabah Vandever

Date: June, 1990

MAJOR CONSIDERATIONS

- A) DOES ANY QUALITATIVE OR QUANTITATIVE INFORMATION EXIST THAT MAY INDICATE AN OBSERVED RELEASE TO AIR, GROUND WATER, SOIL OR SURFACE WATER? Yes

Describe: Scintillometer readings of 100 mR/hr and >100 CPM.

- B) IF THE ANSWER TO # 1 IS YES, IS THERE EVIDENCE OF DRINKING WATER SUPPLY CONTAMINATION OR ANY OTHER TARGET CONTAMINATION (i.e., foodchain, recreation areas, or sensitive environments)? Yes

Describe: Foodchain i.e. livestock grazing at the base of waste piles. Possible groundwater contamination. Threatened/Endangered species in area.

- C) ARE THERE SENSITIVE ENVIRONMENTS WITHIN A 4-MILE RADIUS OR 15 DOWNSTREAM MILES OF THE SITE? Yes
IF YES, DESCRIBE IF ANY OF THE FOLLOWING APPLY:

- Multiple sensitive environments? Numerous surface water bodies. (Ref. 21)
- Federally designated sensitive environment(s)? Yes
Surface water bodies, threatened/endangered species. (Ref. 10,21)
- Sensitive environment(s) downstream on a small or slow flowing surface water body? None (Ref. 1)

- D) IS THE SITE LOCATED IN AN AREA OF KARST TERRAIN? No

Describe:(Ref. 22,23)

- E) IS THE AQUIFER UNDERLYING THE SITE A "SOLE SOURCE" AQUIFER AS DESIGNATED ACCORDING TO SECTION 1424(e) OF THE SAFE DRINKING WATER ACT? No

Describe: (Ref. 7)

- F) DOES ANY QUALITATIVE OR QUANTITATIVE INFORMATION EXIST THAT PEOPLE LIVE OR ATTEND SCHOOL ON ONSITE CONTAMINATED PROPERTY? Yes

Facility Name: Nanabah Vandever Uranium Mine, Abandoned

Location: Haystack Mountain, NM

NM 0986669109

EPA Region: VI

Person(s) In Charge of the Facility: Vandever Heirs, BIA, NMOSM

BIA Realty

Crownpoint, NM 87313

Name of Reviewer: Tom Morris

Date: 6/28/90

General Description of the facility:

(For example landfill, surface impoundment, pile, container; types of hazardous substances; location of the facility; contamination route of major concern; types of information needed for rating; agency action, etc.)

An abandoned Uranium mine site with associated ore waste piles left in place. Waste piles suspected of containing radioactive progenies Rn, Ra, Th, Bi, & Po and leaching heavy metals Se, Pb, Ar, Ba, Mo, U, & V. Contaminations of surface and ground waters, and direct contact/exposure to animals and humans possibly exist. The location is in a rural setting with one community, 3 wells, & 1 artesian spring within the 4 mile site radius. Further site assessment needed ie. air, sediment, plant tissue analyses to determine extent of contaminant migration off site.

Scores: $S_M = 8.64$ ($S_{gw} = 14.5$ $S_{sw} = 3.7$ $S_a = 0.0$)

$S_{FE} =$

$S_{DC} =$

FIGURE 1
HRS COVER SHEET

SUPERFUND
FILE

DEC 31 1991

REORGANIZED

NAVAJO SUPERFUND OFFICE

~~NAVAJO~~
NANAPAN VANDEVER URANIUM MINE
PRELIMINARY ASSESSMENT REFERENCES

JULY 90

T. MORRIS

SUPERFUND
FILE

DEC 31 1991

REC. ORGANIZED

NM 98669109



7/10
36H-MA

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

THE NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION

NSO-90-78

July, 06 1990

Mark Satterwhite
Superfund Indian Coordinator
U.S. EPA Region VI
1445 Ross Avenue
Dallas, Texas 75202

Dear Mr. Satterwhite:

Enclosed is the Preliminary Assessment (PA) Package for the Nanabah Vandever Uranium Mine, located near Haystack Mountain, New Mexico. This report receives NSO internal approval and is now ready for your review and comment.

Please call myself or Thomas Morris, the Environmental Specialist II who prepared the package, for any questions you may have regarding the report. We would appreciate a response in the form of comments or approval at your earliest convenience. You may reach myself or staff at (602) 871-6859, 6860 or 6861.

Sincerely,

Clara Bia
Navajo Superfund Director

SUPERFUND
FILE

DEC 31 1991

Enclosures

cc: Peter Sam, William Taylor, Superfund Site Assessment Section
Deborah Vaughn-Wright

CROSS REFERENCE TO THE
PRELIMINARY ASSESSMENT SECTION IN
NANA-A-BAN URANIUM MINES, NMD 98666 9109,
VOL. 1. X SA, VOL. 1.



AS 7/10
36H-MA

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

THE NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION

NSO-90-78

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Sincerely,

SUPERFUND
FILE

JAN 09 1992

Clara Bia
Navajo Superfund Director

REORGANIZED

Enclosures

cc: Peter Sam, William Taylor, Superfund Site Assessment Section
Deborah Vaughn-Wright

Cross reference to NANA-A-BAN URANIUM
MINES, NMD 986669109, VOL. 02, FILED
IN SA, VOL. 02.

Superfund Site Strategy Recommendation

Region 6

Site Name: Navajo-Nanabah Vandever Uranium Mine Site Number: NMD986669109

Alias Site Name(s):

Address: 4 miles E NE of PrewitCity/County or Parish/State/Zip: Prewit/McKinley/NM/87313

Recommendation:

- ☐ 1. No further remedial action planned under Superfund.
- ☒ 2. Further pre-remedial investigative action needed under Superfund:

PA _____ Priority: High xx
SSI xx _____ Medium _____
To be performed by NAVAJO

SUPEPFUND
FILE

- ☐ 3. Action may be appropriate under other authority:
NPDES _____ SPCC _____ 404 _____ TSCA _____
UIC _____ SMCRA _____ STATE _____ RCRA _____
OTHER _____

DEC 31 1991

REORGANIZED

Discussion: PA

The abandoned Nanabah Vandever Uranium mine produced 24,638 tons of ore containing .22% Uranium and .18% Vanadium. The ore was transported to the Anaconda Mill in Bluewater, NM during the mining period. The site is recorded as being an open pit; however, no pit was found rather mine tailings are present. The waste piles are suspected of producing surface and ground water leachate and fugitive dusts containing toxic heavy metals and radionuclides. There is potential for contamination of one of the aquifers used and also for contamination of livestock used as food. The site has no containment barriers, or warning signs, and is readily accessible to humans and animals. The nearest resident is 1/4 mile southwest of the site. The access road produced a scintillometer reading of 100 ^{MR}HR/hr compared to a background of 6 ^{MR}HR/hr. A roentgen (R) is a measure of exposure and is roughly equivalent to 1 rem. A high radiation area is any area accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 mrem. Therefore, persons using even the road to the site may be exposed to not only radiation dust but high levels of radiation. The waste piles contain an estimated 208.52 tons of toxic compounds and elements dispersed throughout. There is potential also for radon exposure to individuals in the area. This site is recommended for a high priority SSI.

Copies to (please list) Navajo, 6E-E, 6W-S, ATSDR, 6T-AS

Recommended By: Barbara Driscoll Date: 7/19/90Approved By: Bill Taylor for Betty Williamson Date: 7/19/90

Mr. Steve Cary
Program Manager
Superfund Section
Hazardous Waste Bureau
P.O. Box 968
Santa Fe, New Mexico 87504-0968

Dear Mr. Cary:

Enclosed for your files are the Superfund Site Strategy
Recommendations for the following sites:

<u>SITENAME</u>	<u>EPAID</u>	<u>RECOMMENDATION</u>
Narabah Vandever Uranium Mine	NMD986669109	PA; SSI recommended
Jimmy King #2 Uranium Mine	NMD986667558	PA; No further action
Brown Vandever Uranium Mine	NMD986669117	PA; SSI recommended

If you have any questions about the enclosed material or need
additional information, please call me at (214) 655-6740.

Sincerely,

Barbara Driscoll
Environmental Protection Specialist
Superfund Site Assessment Section (6H-MA)

Enclosure

bcc: Mark Satterwhite (6H-SA)
files

6H-MA:DRISCOLL;BD:8/3/90: COMPAQ A:NM9:X6740

TAYLOR

SUPERFUND
FILE

DEC 30 1991

REG/CA/IZEN

AUG 03 1990

MEMORANDUM

SUBJECT: Superfund Site Strategy Recommendation

FROM: William H. Taylor, Chief
Superfund Site Assessment Section (6H-MA)

TO: Several Addressees

Attached are copies of the Superfund Site Strategy Recommendations for the following sites:

<u>SITENAME</u>	<u>EPAID</u>	<u>RECOMMENDATION</u>
Nanabah Vandever Uranium Mine	NMD986669109 ✓	PA; SSI recommended ✓
Jimmy King #2 Uranium Mine	NMD986667558	PA; No further action
Brown Vandever Uranium Mine	NMD986669117	PA; SSI recommended

If you have any questions about the enclosed material or need additional information, please contact Barbara Driscoll at x6740.

Addressees:

Carl Hickham (ATSDR)
Oscar Cabra (6W-S)
Charles Gazda (6E-E)
Hank May (6T-AS)

Attachment

bcc: files

6H-MA:DRISCOLL;BD: 8/3/90:COMPAQ A:ADDR2

SUPERFUND
FILE

DEC 30 1991

REORGANIZED

AUG 03 1990

Clara Bia
Executive Director
Navajo Superfund Office
P.O. Box 2946
Window Rock, Arizona 86516

Dear Ms. Bia:

Enclosed are the Superfund Site Strategy Recommendations (SSSR) except for the workplans for the following sites:

<u>Site Name</u>	<u>EPA ID</u>	<u>Recommendation</u>
Nanabah Vandever Uranium Mine	NMD986669109	PA; SSI recommended ✓
Jimmy King #2 Uranium Mine	NMD986667558	PA; No further remedial action
Brown Vandever Uranium Mine	NMD986669117	PA; SSI recommended
Begay #1	NMD986667426	SSI workplan; Approved
Begay #2	NMD986667509	SSI workplan; Approved

If you have any questions or need additional information, please contact me at (214) 655-6740.

Sincerely,

Barbara Driscoll
Environmental Protection Specialist
Superfund Site Assessment Section (6H-MA)

Enclosure

bcc: Mark Satterwhite (6H-SA)

files
6H-MA: DRISCOLL:BD:8/3/90:COMPAQ A:BIA1:X6740

SUPERFUND
FILE

TAYLOR

WA
8/3/90

DEC 30 1991

REORGANIZED

SITE NAME : NAVAJO - H VANDEVER URANIUM MI
SITE LOCATION: PREWITT
SITE NUMBER : NMD986669109
LOG NUMBER : 89

ROUTE SLIP
HAZARDOUS WASTE SITE - INSPECTION REPORT

	INITIALS	DATE	TIME (HOURS)
1. LEN PARDEE	LP	8/17/90	1.0
2. TOM LOVE	TL	8/28/90	—
3. HERB DAVIS (Cover memo, Xerox copies of report, log out of file, file) (Copies to Hickam, Wright 6H-ES)	KD	8/22/90	3.30

FILE CODE: SFD-24-1-3

1192

T I O N R E P O R T R E V I E W
P O T I T I O N H A Z A R D O U S W A S T E S I T E

SITE NAME : NAVAJO - KANABAH VANDEVER URANIUM MINE

LOCATION : PREWITT

SITE NUMBER: NMD986669109

SURVEY DATE: ___/___/___ INSPECTED BY: STATE FIT TAT OTHER: _____

LABORATORY : ___CLP___EPA___OTHER_____

RECEIVED FROM: _____ DATE RECEIVED: 8/6/90

SAMPLE TYPE(s):

SOIL	SURFACE WATER	GROUND WATER	DRINKING WATER
off / on -site	off / on -site	off / on -site	off / on -site

CONTAMINANT(s): Organics Inorganics Radionuclides Microbiological

FOLLOW UP (Y/N):

___ (Re)Sampling Requested	___ Locate Drinking Water Sources
___ Further Action is URGENT	___ Keep Site Active ("N"=No Further Action)
	___ Concur with Report Recommendations

SUMMARY:

I agree with the report recommendation that a screening site inspection be conducted. Public drinking water wells involved with this site should already have been sampled for gross alpha and radium and this data should be reviewed as part of the SSI. Laboratory reports should be available from the Indian Health Service in Window Rock, Arizona for Navajo wells or with NMEID Drinking Water in Santa Fe for public wells not on Indian land.

SUPERFUND
FILE

DEC 30 1991

REORGANIZED

Concurrence:

F. Warren Norris 8/20/90

Len Parde

ENGINEER/REVIEWER

8/17/90



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION VI
1445 ROSS AVENUE, SUITE 1200
DALLAS, TEXAS 75202

Barbara

DATE: *8/22/90*

MEMORANDUM

SUBJECT: Potential Hazardous Waste Site - Site Inspection Report

FROM: O. Thomas Love, Jr., P.E.
Acting Chief
Water Supply Branch (6W-S)

OTL *Bar*

TO: Betty Williamson
Chief
Superfund Management Branch (6H-M)

In response to the CERCLA investigation reports which you recently sent to the Water Supply Branch, I am attaching our comments. Thank you for the opportunity to review these documents.

Attachment:

Site Name: NAVAJO-NANABAN VANDEVER
Site Location: FEW, H
Site Number: NMD 906 669 109

cc: Carl Hickam (6H-ES)

SUPERFUND
FILE

DEC 30 1991

REORGANIZED

**NAVAJO-NANABAN URANIUM
MINES**
11/15/90 666 9109

407.4

110 nabah

11

Mr. Steve Cary
Program Manager
Superfund Section
Hazardous Waste Bureau
P.O. Box 968
Santa Fe, New Mexico 87504-0968

Dear Mr. Cary:

Enclosed for your files are the Superfund Site Strategy Recommendations for the following sites:

<u>SITENAME</u>	<u>EPAID</u>	<u>RECOMMENDATION</u>
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Jimmy King #2 Uranium Mine	NMD986667558	PA; No further action
Brown Vandever Uranium Mine	NMD986669117	PA; SSI recommended

If you have any questions about the enclosed material or need additional information, please call me at (214) 655-6740.

Sincerely,

Barbara Driscoll
Environmental Protection Specialist
Superfund Site Assessment Section (6H-MA)

Enclosure

bcc: Mark Satterwhite (6H-SA)
files

6H-MA:DRISCOLL;BD:8/3/90: COMPAQ A:NM9:X6740

TAYLOR

CONTACT REPORT

Meeting: ()

Telephone: (X)

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Davy Morris, Director, BIA Realty, Crownpoint, NM

PHONE: 505-786-6116

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 6/5/90

SUBJECT: Current owner, Nanabah Vandever allotment

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

Nanabah Vandever is deceased and the allotment has been probated to 31 heirs. Because of the Right to Privacy, further information is attainable by written request and signing a Freedom of Information form with the BIA Realty office in Crownpoint, NM.

REFERENCE #3

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT

Meeting: (X)

Telephone: ()

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Patrick Antonio, Hydrogeologist, NSO

PHONE: 602-871-7331

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 5/24/90

SUBJECT: Groundwater contamination possibilities from Nanabah
Vandever Uranium mine waste piles

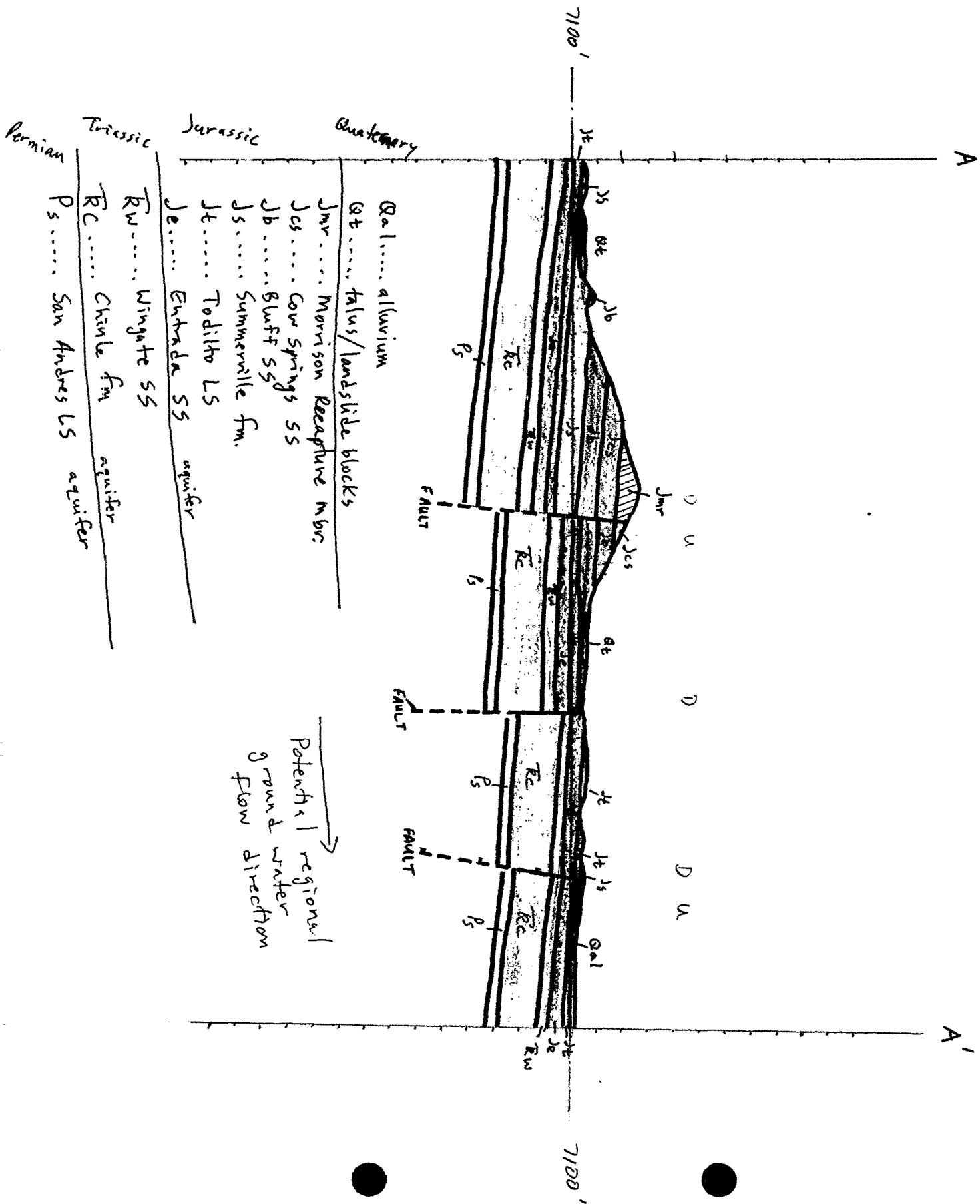
INFO.

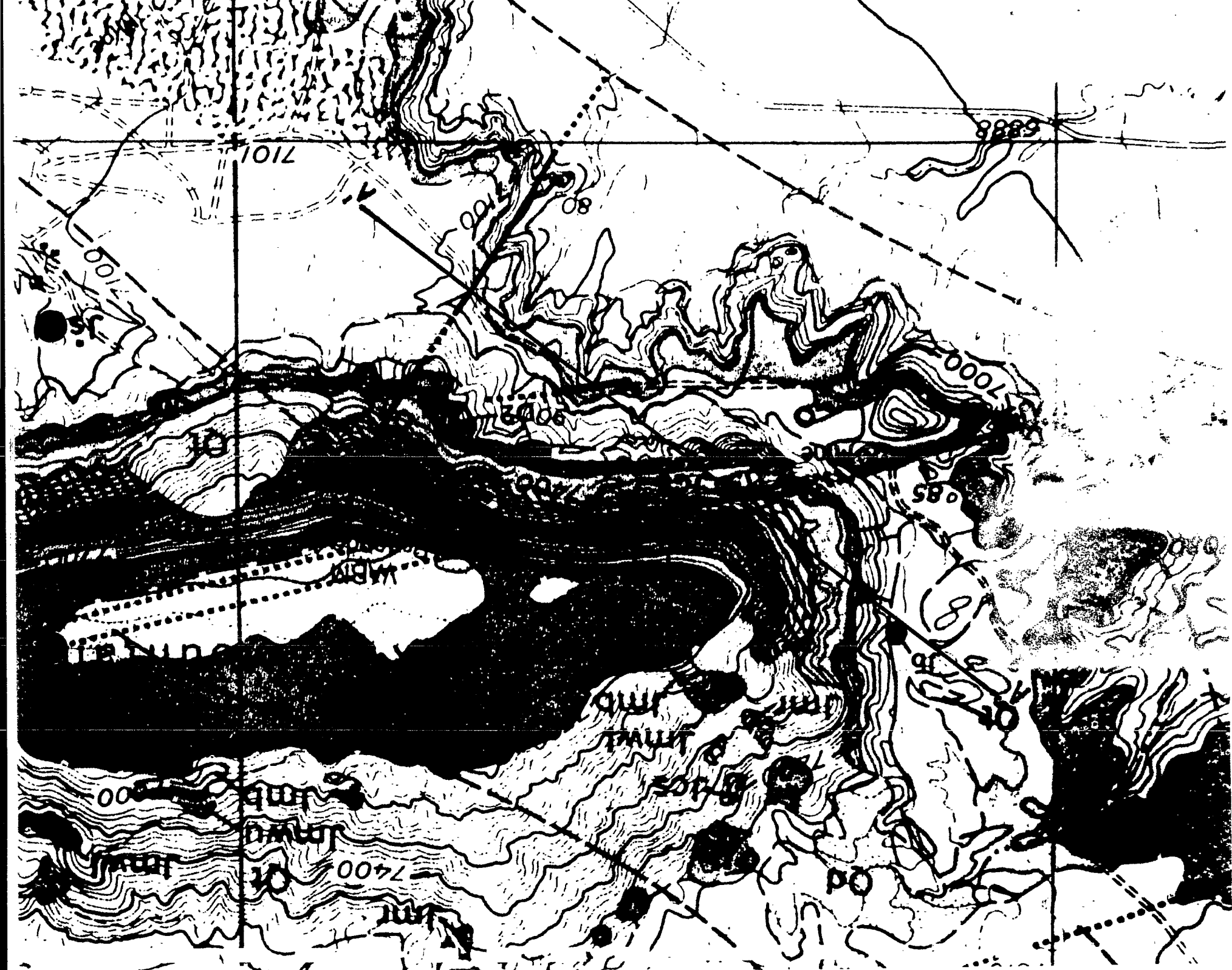
REPOSITORY:

CONTACT SUMMARY REPORT:

The Entrada aquifer is suspect due to its depth to water.

The Sonßela and Chinle aquifers are probably not affected due to their depth.





INFLUENCE OF FAULTS ON GROUND WATER

Faulting of sedimentary rocks can create vary complex hydrogeologic systems, in which determination of the location of recharge and discharge zones and flow systems is confounded.

Fault zones can act as either barriers to ground water flow or as ground water conduits, depending on the nature of the material in the fault zone----space within the fault surfaces.

If the fault zone consists of finely ground rock and clay, the material may have a very low hydraulic conductivity----meaning water will have difficulty moving through the fault zone.

In consolidated rocks (sandstones, limestones, etc.), faults are more often ground water conduits. Broken and brecciated rock in the fault zone may have a high porosity and hydraulic conductivity ----meaning water will move freely through the fault zone.

The presence of faulting may have no significant effect on hydrogeology. Faults with a very small movement will ususally have the same hydraulic characteristics as the parent rock. Brecciated fault zones are potential conduits for movement of hydrothermal solutions, and faults can become mineralized possibly sealing the fault and losing the original high conductivity.

OPINION (for Tom Morrissey): Since the stratigraphy is composed of mostly of sedimentary limestone and sandstone formations, no drastic influences (barriers) on ground flow is expected. The only item of note is that recharge from infiltration through above formations or from surface outcrops may be slightly hindered upon contact with a fault, espeically if the rocks on each side of the fault are of different formations. Extra time will be needed for ground water to flow through a less permeable formation or for ground water to lower to a more suitable permeable formation.

If there is sufficient artesian pressure in the aquifer and the fault zone has favorable conductivity, ground water may rise up through the fault and emerge as a spring or seep at surface level. Just the opposite, faults can also transmit contamination to lower, previously uncontaminated aquifers.

A fault would have more of an influence if a well was drawing right near a fault zone.

REFERENCE #4

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT

Meeting: ()

Telephone: (X)

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Daryll Begay, Ranger, Navajo Fish and Wildlife

PHONE: 602-871-6451

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 6/8/90

SUBJECT: Fisheries, Recreational Areas, Haystack Mountain, NM

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

No Fisheries

No Navajo hunt units or designated recreational areas in the Haystack area

REFERENCE #5

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

CONTACT REPORT #

Meeting: (X)

Telephone: ()

Other: ()

CONTACT LOCATION: Residence of contact

ADDRESS: Crownpoint, NM

PERSON CONTACTED
AND TITLE : Elsie Brown, Field Nurse, Indian Health Service

PHONE: 505-786-5291

FROM (Contacting
Party) : T. Morris, Environmental Spec., NSO

DATE : 5/26/90

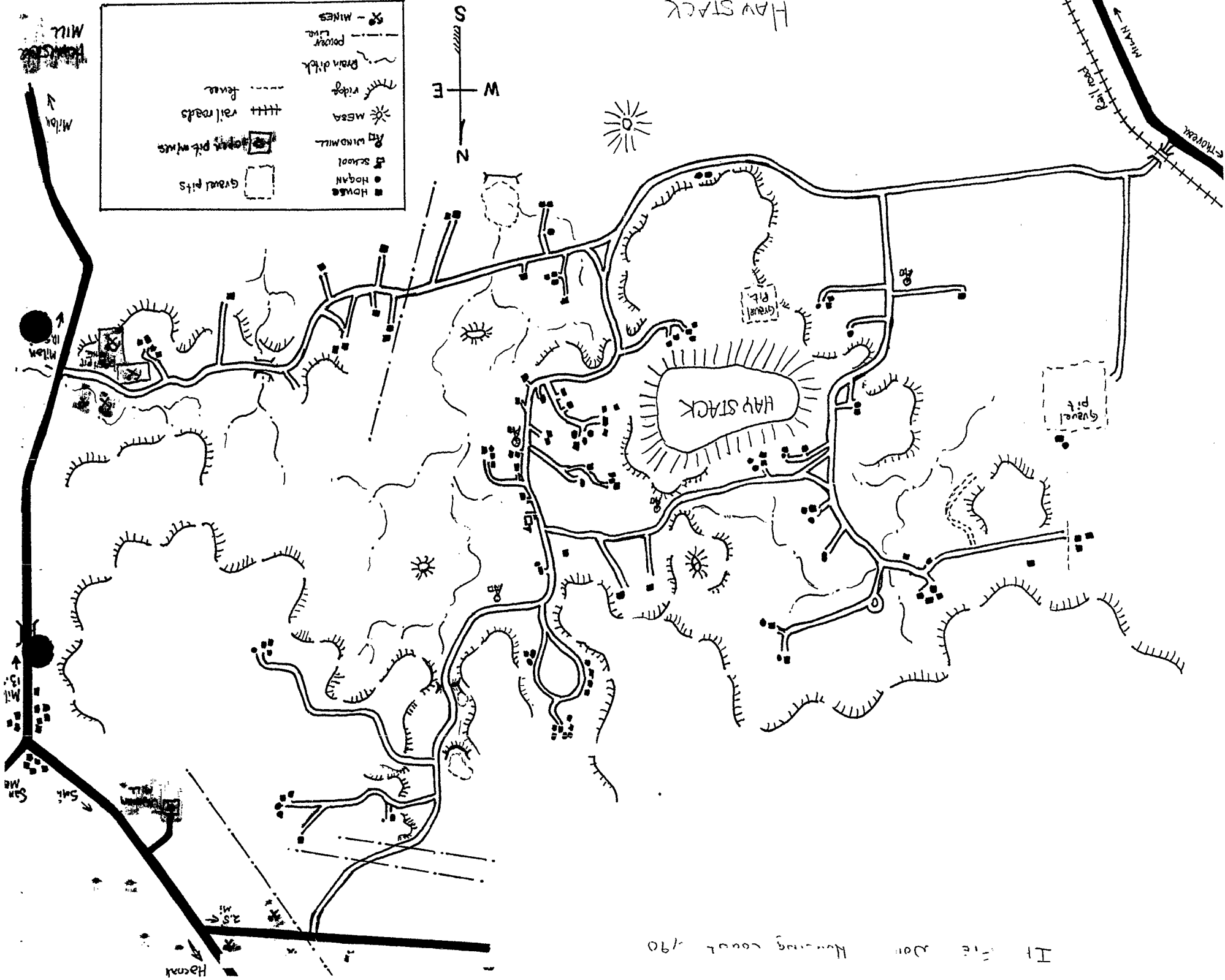
SUBJECT: Residence count, Haystack Mountain area

CONTACT SUMMARY REPORT:

The attached map was drawn by a field worker under Ms. Brown's supervision. This map shows the residences around Haystack Mountain. The gravel pits shown on the map are actually abandoned Uranium mines in the Todilto limestone.

II
11
2001

How many buttons



REFERENCE #6

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT

Meeting: ()

Telephone: (X)

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: David Baggett, Environmental Specialist, New Mexico
Health and Environment Dept.

PHONE: 505-827-2943

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 5/21/90

SUBJECT: Bioaccumulation of radionuclides in livestock, Haystack, NM

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

No studies done at Haystack

See Attached: "Radionuclide Levels In Cattle Raised Near Uranium
Mines and Mills In Northwest New Mexico"

**RADIONUCLIDE LEVELS IN CATTLE RAISED NEAR
URANIUM MINES AND MILLS IN NORTHWEST
NEW MEXICO**

BY

**SANDRA C. LAPHAM, M.D., M.P.H. and JERE B. HILLARD, M.S.
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION**

AND

**JONATHAN M. SAMET, M.D., M.S.
NEW MEXICO SCHOOL OF MEDICINE**



JUNE, 1986

**P.O. BOX 968
SANTA FE, NEW MEXICO 87504-0968**

FUNDING FOR THIS STUDY WAS PROVIDED BY THE NEW MEXICO LEGISLATURE

ACKNOWLEDGEMENTS

We wish to acknowledge the New Mexico legislature for providing public funds necessary to conduct this study.

The authors thank Paul Hahn, Wayne Bliss, and all of the United States Environmental Protection Agency staff who assisted the EID in collecting specimens and performing laboratory quality control analyses. We also thank staff of the Indian Health Service, especially Wayne Moeller, Don Payne, and Don Bitsilly, and Dr. Chandrasekaren and Kathy Burnham of Eberline Laboratory, and Dave Baggett and Kent Breese of the EID for their assistance in this project.

We thank Richard Holtzman of the U.S. Nuclear Regulatory Commission, Jim Ruttenber of the Centers for Disease Control, Kathy Burnham of Eberline Analytical Laboratory, Charles Dowell, Charles Reaux and Wayne Moeller of the Indian Health Service, Jim McInroy of Los Alamos National Laboratories, Hank May, Paul Hahn, Wayne Bliss, and Mike Mardis of the Environmental Protection Agency and Stuart Castle and Ken Hargis of the New Mexico Health and Environment Department for their review of this manuscript.

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INTRODUCTION

The development of a large uranium mining and milling industry in the Colorado Plateau during the past 30 years has led to concern about adverse health effects of these industrial activities on nearby human populations. Few studies have addressed radionuclide concentrations in domestic animals raised near uranium mines or mills. Yet evidence from two previous investigations indicates that there may be contamination in the food chain leading to humans.

In the first study, Holtzman et al. collected animals near Grants, New Mexico, in 1979, and found that muscle, lung, and kidney tissue from wild rabbits foraging near uranium mill tailings piles had higher mean concentrations of radium-226 (Ra-226) than did control rabbits (1). They also showed that grass irrigated with mine dewatering effluent had elevated Ra-226 concentrations and that cattle grazing on land irrigated by mine water had higher levels of both Ra-226 and radioactive lead, compared to controls.

Another study was conducted in 1979 at Church Rock, New Mexico, in response to an accidental spill of uranium tailings liquid into a stream of mine dewatering effluent (2). Investigation into the potential human health consequences of the accident included radiochemical analyses of muscle, liver, and kidney tissue from livestock that grazed near the banks of the stream and drank mine water. Radionuclide concentrations were higher than controls, both in animals exposed to the spill and in those exposed only to uranium mine dewatering effluent.

In 1983, New Mexico had nine operating underground uranium mines (3). There are seven conventional uranium-recovery facilities currently under licensure by the New Mexico Radiation Protection Bureau, Environmental Improvement Division (EID), although only two have operated in recent years (4). Seven large uranium tailings piles in the state cover 1355 acres (5), and the Jackpile open pit uranium mine is 2656 acres in size (6). All of these mines and mills are located in the Grants mineral belt, an area of about 4000 square kilometers (2500 square miles) (Figure 1). Since grazing land in this area of New Mexico supports about seven cattle per square mile (7), 17,500 animals potentially could be exposed to products of the uranium mining and milling industry.

We conducted the present investigation to determine whether cattle grazing in areas with uranium mining and milling activity have tissue concentrations of radionuclides that are significantly above background, and whether eating this tissue regularly could expose humans to excessive internal radiation doses. Existing U.S. standards for the nuclear fuel cycle limit radiation doses to members of the public to 25 millirem (mrem) per year to any organ except thyroid, but exempt radiation doses from uranium mine effluent and from radon and its daughters (8). Evidence of food chain contamination near mines and mills could raise questions as to the adequacy of these standards.

METHODS

Study Site Selection.

Two areas in the Ambrosia Lake region, an 80 square kilometer (km) valley

located in the Grants Mineral Belt (Figure 1) of northwestern New Mexico, were chosen for this study because Ambrosia Lake has been the site of intensive uranium mining and milling since the late 1950's. Numerous tunnels undermine the area, which is dotted with ventilation shafts (Figure 2). A large uranium milling facility, which Kerr-McGee opened in 1957, is licensed to process 7000 tons of ore per day. There are two uranium mill tailings piles in the valley. The Kerr-McGee pile was active until 1984 and is 245 acres in size, while the other (Phillips) pile, covering 105 acres, has been inactive since 1963. Continuous discharges of mine dewatering effluent, currently treated by ion exchange plants to remove Ra-226 and natural uranium, are available to domestic animals and provide the only water source for some. The Kerr-McGee tailings piles and the associated lagoons are fenced to prevent access. However, animals do have access to liquids collecting on top of the Phillips pile.

It was estimated that 122,000 curies of radon gas were released per year in the 1970's from mine vents in Ambrosia Lake (9). In addition, radon is released from the Kerr-McGee tailings pile, the Phillips tailings pile, numerous mine waste piles, and from soil in the area. The total radon released per year to the atmosphere was estimated to be 157,200 curies (10). Results of a 1978-1979 study conducted in Ambrosia Lake by Buhl et al. indicated that the state and federal radon limit of 3.0 picocuries per liter (pCi/l) above background (11, 12) was exceeded at four of nine air sampling stations (10). The overall two year average for all the stations (4.0 pCi/l) also exceeded the limit. However, this limit exempts contributions from any mining activities. Subsequent monitoring of radon levels in Ambrosia Lake between 1980-1984 (4) revealed similarly elevated

ambient air radon concentrations (Figure 2). Thus, cattle in the area are potentially exposed to radon and its decay products, windblown tailings or ore, and mining effluent.

The Church Rock study site is approximately 20 km north of Church Rock, New Mexico and 45 km west of Ambrosia Lake (Figure 1). A United Nuclear Corporation (UNC) uranium mill is located at the site and is licensed to process 3000 tons of ore per day. However, this facility has not processed ore since May, 1982. Two underground mines currently discharge effluents which form a perennial stream available to local animals (Figure 3). In addition, an ion exchange plant downstream of the mill discharges liquid effluent into the Rio Puerco. In 1979, a breach of the UNC mill tailings impoundment released 355 million liters of liquid wastes contaminated with toxic elements and radionuclides from the uranium-238 decay series (2). Therefore, animals at this study site were potentially exposed to accidental releases and chronic discharges.

Mean ambient air radon concentrations and standard errors in the Church Rock region were 1.5 ± 0.3 and 1.3 ± 0.2 pCi/l for 19 and 17 individual samples respectively, taken in 1980 at two stations within 0.5 km of the UNC tailings impoundment. From August, 1984 to February, 1985, radon averaged 1.7 ± 0.2 and 1.5 ± 0.2 pCi/l from 14 samples collected at the same 1980 stations. Radon concentrations measured in 1980 averaged 0.5 ± 0.1 pCi/l five km from the tailings facility (13).

Crownpoint, the control study site, is also in the Grants Mineral Belt

approximately 40 km northwest of Ambrosia Lake and 22 km east of Church Rock. The nearest active uranium impoundment is an in situ pilot plant approximately 8 km to the northeast. An undeveloped mine shaft is located 5 km southeast of the control animals' grazing site. There are no other uranium industrial activities in the area. Thirty-seven radon measurements taken at distances of 0.8-5 km from the undeveloped mine and 5-8 km from the in situ pilot plant have averaged 0.15 ± 0.02 pCi/l (10). These radon concentrations are consistent with averages from unmined areas in the Grants Mineral Belt (10).

Natural background radioactivity was not measured in Ambrosia Lake or Church Rock prior to start-up of the mining and milling operations at these sites. However, the Crownpoint area of New Mexico is rich in underground uranium and is slated for uranium mine development in the future if the price of uranium increases. Therefore, it is an area with potentially high background radiation, yet is an undisturbed area in the Grants Mineral Belt. For these reasons Crownpoint represented an appropriate baseline for comparison to animals raised near uranium mines or mills.

Cattle Selection and Tissue Sampling.

All cattle were purchased and slaughtered in October, 1983. Five cattle were obtained from each of two ranchers in Ambrosia Lake. Group 1 cattle grazed in a 4.4 square km fenced area that had frequently been flooded by dewatering effluent from a nearby uranium mine. The ion exchange plant (Figure 2) that treated this water to remove uranium and Ra-226 was built in 1976 but has not been regulated by the EID due to pending litigation

(4). Group 1 cattle's only water source was mine dewatering effluent. Group 2 cattle grazed in a much larger open area and had access to surface impoundments as well as dewatering effluent. Seven cattle were purchased in Church Rock (Figure 3) and ten animals were purchased in the control area near Crownpoint. Information on sex, birth date, place of birth, health, and food and water sources, was obtained for all animals at the time of purchase.

Exposed and control cattle were transported to an abattoir and sacrificed within 48 hours. A United States Environmental Protection Agency (EPA) veterinarian and New Mexico EID staff obtained the specimens, while taking precautions to prevent cross-contamination of tissues. Nondisposable equipment was washed thoroughly between sample collections. Specimens were individually bagged and identified. Tissues obtained from each animal for analysis included several kilograms of the upper thigh muscle, the right lobe of the liver, a whole kidney, and the entire right femur. Tissues were refrigerated and transported to the analytical laboratory for analysis. Backup and quality control specimens (Appendix A) were frozen.

Environmental Sampling.

Composite samples of grass and soil were collected from grazing areas in Ambrosia Lake and Church Rock (Figure 2, 3) and from the control area. Grasses in a square meter area were clipped at soil level and analyzed unwashed. Soil samples were collected in each vegetation quadrat to a depth of 5 cm and a volume of 600 cm³.

Water samples were obtained from all water sources available to the study cattle in Ambrosia Lake and Crownpoint. Water was sampled from the Pipeline arroyo and from the Rio Puerco in Church Rock. Approximately 3.8 liters of unfiltered water was collected at each source and treated with 20 ml of concentrated nitric acid to form a 0.5% HNO_3 solution. This technique prevented plating of radionuclides on the sample container.

Laboratory Methods.

Eberline Corporation in Albuquerque, New Mexico performed the radiochemical analyses. Each tissue was analyzed for uranium-238 (U-238), uranium-234 (U-234), thorium-230 (Th-230), Ra-226, lead-210 (Pb-210), and polonium-210 (Po-210). In addition, split samples of muscle, liver, and kidney tissues from two cattle chosen randomly from each of the three areas were analyzed for the above radionuclides by the EPA, Environmental Monitoring Systems, Las Vegas, Nevada, (EPA-Las Vegas) for quality control purposes (Appendix A).

The methods for measuring radionuclide concentrations in animal tissues and environmental samples were derived from published EPA and United States Department of Energy analytical procedures (14, 15). Tissue samples were weighed (Table 1) and dried at 105°C for approximately 24 hours. About 200 grams (gm) of the dried sample were ashed in a muffle furnace at 500°C , then wet ashed repeatedly with concentrated nitric acid (HNO_3) and hydrogen peroxide repeatedly to dissolve the sample. The final residue was dissolved in 8 normal HNO_3 and diluted to a measured volume. Aliquots of this solution were used for U-238, U-234, Ra-226, and Th-230 analyses.

Uranium and thorium were then measured by alpha spectroscopy, and Ra-226 was measured by radon de-emanation.

For the Pb-210 and Po-210 analyses, approximately 200 gm of the dried sample were digested (wet ashed) repeatedly with concentrated nitric acid, hydrochloric acid (HCl) and hydrogen peroxide at 85°C until the entire sample was completely oxidized and dissolved. The sample was then dissolved in 1 normal HCl to a measured volume. Aliquots of this solution were analyzed for Po-210 by electrodeposition and alpha counting, and for Pb-210 by bismuth-210 (Bi-210) separation and beta counting. Appropriate internal tracers and stable carriers were added to determine the chemical and radiochemical recovery fractions. The lower limits of detection (LLD) are presented in Table 1.

Bone samples were weighed and then cut into twelve approximately equal sections of about 3 centimeters in thickness. Alternate sections were combined. One combined sample was used for the determination of U-238, U-234, Ra-226, and Th-230. The remainder was analyzed for Po-210 and Pb-210, according to the above methods.

All environmental samples (vegetation, soil, and water) were analyzed for U-238, U-234, Th-230, Ra-226, Pb-210, and Po-210 using the same methods for measuring radionuclide concentrations as were used for tissue specimens. Tissue and bone concentrations of Po-210 were corrected for radioactive decay and the ingrowth of Po-210 from Pb-210 with the following equation:

$$\text{Corrected Po-210} = \frac{\text{Po-210 at separation date} - (1 - e^{-\lambda t}) \text{ Pb-210 at separation date}}{e^{-\lambda t}}$$

Where λ = decay constant for Po-210

t = time between sample collection and Po-210 sample analysis
when Po-210 was radiochemically separated from Pb-210.

If the corrected Po-210 concentration was a negative number, it was assigned a value of zero.

Methods used at the EPA-Las Vegas laboratory for detecting radionuclides in animal tissues have been previously described (2), with the exception that Th-230 recoveries were determined using a thorium-229 tracer, followed by alpha spectrometry. The major difference between procedures followed by the two laboratories involved the analysis of Pb-210. Technicians at Eberline counted the Bi-210 decay product of Pb-210 using beta detection equipment while those at the EPA-Las Vegas laboratory counted the Po-210 formed from Pb-210 decay using alpha spectrometry. In both laboratories, an error factor was calculated and reported as two standard deviations of the counting rate (16). Negative radionuclide concentrations were reported on occasion and resulted from subtraction of background counts from sample counts. Each laboratory also used its own protocol for assuring quality control.

Statistical Methods.

Statistical analysis was performed on the computerized data set using the Statistical Analysis System (17). Radionuclide concentrations in cattle

tissue and bone, and concentrations in the environmental samples from each of the two Ambrosia Lake groups, Church Rock, and Crownpoint were compared using both parametric (multiple analysis of variance (MANOVA) with General Linear Models (G.L.M.) for unequal sample sizes, Duncan's multiple range test) and nonparametric (Kruskal-Wallis and Wilcoxon's two-sample) statistical tests. In the MANOVA approach radionuclide concentrations were the dependent variables. Location (Ambrosia Lake Group 1, Group 2, Church Rock or Crownpoint) was the independent variable. Analyses of cattle tissue were performed with and without age added to the model to determine possible age dependent effects.

Since the sample size in each group was small, it was not possible to determine whether the data were normally distributed. Therefore, nonparametric tests were performed. The Kruskal-Wallis test was used to determine whether any of the three exposure groups or the control group differed significantly ($p < 0.05$). If significant differences were found, the Wilcoxon's rank-sum test, with continuity correction of 0.5, was used to compare each exposure group to the Crownpoint control group.

A discussion of the quality control comparisons is given in Appendix A. Results of split sample testing were compared using a two-tailed paired-sample t-test (18).

RESULTS

Cattle Data.

All of the cattle but one were female. The average age of Ambrosia Lake

Group 1 cattle was 5.0 (range 4-6 years). Ambrosia Lake Group 2 cattle were two- and three-year-olds with a mean age of 2.4. The mean age of the Church Rock cattle was 2.6 (range 2-5 years) and that of the Crownpoint controls was 4.8 (range 3-7 years). Except for one animal purchased as a calf from another owner, all animals were born and raised in the described areas. The owner of Ambrosia Lake Group 1 cattle stated that some of the animals in his herd were not gaining weight properly and reproduced poorly. The other owners reported their animals to be in good health. Animals from all four groups received supplemental fodder during winter. All seventeen animals in the three exposed groups and none of the ten animals in the control group had access to uranium mine dewatering effluent.

Radionuclide Concentrations in Cattle.

Mean radionuclide concentrations in muscle tissue from Ambrosia Lake Groups 1, 2, and from Church Rock cattle were similar to corresponding controls, with the exception that Ra-226 and Po-210 were significantly increased in Group 1 cattle and U-234 was elevated in Church Rock cattle (Table 2). Mean radionuclide concentrations in the majority of the liver, kidney, and femur samples were significantly above control levels among both Ambrosia Lake Group 1 and Group 2 cattle. Liver and femur from Church Rock cattle were significantly elevated in U-238 and U-234, and femur was elevated in Ra-226. Levels of Th-230 were generally higher among Church Rock cattle than controls but these elevations were not significant statistically. When age was added to location as an independent variable in the MANOVA model, the effect of location on mean radionuclide concentrations was unchanged, although differences between mean muscle Ra-226 and kidney Po-210 concentrations in Ambrosia Lake Group 1 cattle versus the remaining

groups became less significant statistically ($p=0.07$ and 0.05 , respectively). Age did not alter significance levels in the other analyses.

Radionuclide Concentrations in Environmental Samples.

Radionuclide levels in soil sampled from Ambrosia Lake Group 1 were significantly elevated over those of controls. Concentrations of ^{230}Th and ^{226}Ra were significantly higher than controls in vegetation samples (Table 3). Concentrations of ^{230}Th and ^{226}Ra in vegetation from Ambrosia Lake Group 2 were also significantly higher than controls. Mean radionuclide concentrations in soil from Ambrosia Lake Group 2 were several times higher than those of controls, but the differences did not attain statistical significance. Soil from sampling sites 11-13 in Group 1 and sites 2, 4, and 5 in Group 2 had much higher radionuclide levels than did soil collected at the other sites in the respective grazing areas (Appendix, Table B-2). Soil samples from Church Rock had higher mean radionuclide concentrations than those from Crownpoint but these levels were not significant statistically (Table 3). Radionuclide content of vegetation from Church Rock was higher than controls in ^{226}Ra and ^{210}Po but these difference did not attain statistical significance.

Water samples collected from Ambrosia Lake Group 1 and from Church Rock had higher mean concentrations of ^{238}U and ^{234}U than controls. Ambrosia Lake Group 2 water contained higher levels of these radionuclides than controls but the differences were not significant statistically.

DISCUSSION

Summary of Study Results.

The principal objective of the present study was to determine whether radionuclide concentrations in the tissues of cattle raised near uranium mines and mills were significantly higher than those of unexposed animals. Results indicated that all three groups of cattle exposed to uranium mine and mill discharges and wastes had elevated tissue radionuclides compared with controls.

Cattle exposed to the most active mining and milling area, Ambrosia Lake, were considerably closer to mines and mills than those from Church Rock. Ambrosia Lake Group 1 cattle grazed in an area with the highest measured concentrations of soil radionuclides, and dewatering effluent was their only water source. Water samples had higher levels of U-238 and U-234 than controls. These animals also were raised where ambient air radon levels were above background.

Most of the liver, kidney, and bone tissues from Ambrosia Lake Group 2 cattle also contained elevated radionuclide concentrations. These animals grazed in an area with elevated ambient radon concentrations. A portion of their grazing area abutted a uranium mill and tailings pile. However, these cattle roamed over a very large area and drank rainwater in addition to mine dewatering effluent. Environmental sampling revealed mean radionuclide concentrations in soil, vegetation, and water that were intermediate between Ambrosia Lake Group 1 and the controls.

Tissues from Church Rock cattle showed lower radionuclide levels than were found in cattle from Ambrosia Lake. These animals had exposure to much lower levels of ambient air radon (most levels were probably background). Most radionuclide concentrations in vegetation also were similar to background levels. The primary exposure of these cattle was to uranium mine dewatering effluent. Water samples taken from Church Rock were elevated in U-238 and U-234. Correspondingly, cattle tissue from Church Rock was elevated in U-238 and U-234.

Study Limitations.

This study had several limitations. First, only a small number of cattle were tested from each area. Since there was variability between radionuclide concentrations measured in animals from each group, the standard errors were large. Second, there was variability in the results of split sample testing, especially the Po-210 measurements (Appendix A). It is possible that the Po-210 concentrations reported by Eberline Laboratory may be twice as high as the true values.

A third problem was that the radionuclide concentrations measured in the environmental samples may not have been representative of those to which the cattle were actually exposed. The sample numbers were small and samples were taken at only one point in time. Since the cattle were living in their respective areas for two to seven years, many samples of soil, vegetation, and water, tested periodically, would have been required to characterize radionuclide levels in the cattle's environments.

The fact that only single samples were collected is a problem, especially

in interpreting the results of water analyses. Ion exchange plants treated the mine water drunk by cattle from both Ambrosia Lake Groups and from Church Rock. However, concentrations of contaminants in treated effluents may have fluctuated, depending on how well and how consistently these plants were maintained and operated. Untreated uranium mine water may contain significant levels of U-238 chain radionuclides. Gallaher and Goad, in a study of mine water in New Mexico, reported a median of 170 pCi/l Ra-226 and 5.4 mg/l uranium (equivalent to about 1800 pCi/l each of U-238 and U-234) (19). Thus, if ion exchange plants were not operating effectively, study cattle could have ingested water containing much higher radionuclide levels than those given in the present report.

Finally, only two of a possible four groups of cattle were sampled from Ambrosia Lake. One group not sampled was considered to be more heavily exposed to uranium activities than those that were sampled. Therefore, the results of this study should not be considered to completely describe the tissue levels of all animals grazing in Ambrosia Lake.

Estimation of Doses from Cattle Tissue Ingestion and Cancer Risk Estimates.

The internal dose commitment received when a person ingests cattle tissue for one year with known radionuclide concentrations was estimated for all four groups using dose conversion factors of Dunning (20). These conversion factors were used because they are based on the most current metabolic models for the uptake and elimination of radionuclides. Mean tissue concentrations for each exposed group and the control group were used for the calculations, and dose commitments were estimated for a 50 year period following one year of ingestion. F_1 uptake factors for absorption of

specific radionuclides across the human gut were 0.05 for U-238 and U-234, 0.0002 for Th-230, 0.2 for Ra-226, 0.2 for Pb-210, and 0.1 for Po-210 (21). A quality factor of 20 for alpha radiation was assumed for all dose conversion factors, in accordance with recommendations of the International Commission on Radiological Protection (ICRP) (22). We estimated doses to human kidney, liver, endosteum, and red marrow.

To estimate cancer risks from ingestion of cattle tissue, total picocuries of each radionuclide ingested per year were calculated and converted to mrem per year using the effective dose equivalents of Dunning (20). The total effective dose equivalent for each scenario was then multiplied by the ICRP risk coefficient of 125×10^{-6} per rem to estimate the expected number of cancer deaths (22). Lifetime cancer risks were expressed as the number of excess cancer deaths per million population attributable to the radiation dose received from one year and 20 years of ingestion.

Internal radiation doses and cancer risks were calculated according to three scenarios of tissue consumption. Scenario 1 assumed that a family living in the described areas would slaughter and ingest all the edible parts of an animal, including its liver and kidneys, over a one-year period. This scenario assumed a total beef consumption of 78 kilograms (kg) per year per individual, the average per capita yearly meat consumption in the United States (23) and a dietary proportion of muscle, liver, and kidney comparable to that organ's percentage of the combined average weight of beef muscle, liver, and kidney, 74 kg (94.8%), 2.7 kg (3.4)%, and 1.3 kg (1.87%) respectively (2).

Scenario 2 assumed that a person ingested 78 kg of muscle per year from each area but did not eat liver or kidney. Scenario 3, a worst case estimate, assumed that a person ate higher percentages of liver and kidney. These percentages were the 99th percentile of reported consumption from a 1984 dietary survey of 767 adult Hispanic and Non-Hispanic white New Mexicans selected randomly for a study (24). Worst case estimates assumed a liver consumption of 13.1 kg per year and a kidney consumption of 2.6 kg per year, with muscle constituting the remainder of the 78 kg yearly meat intake.

In scenario 1, the annual ingestion of muscle, liver, and kidney from control animals incurred a 50 year dose commitment of 25 mrem to the kidney and 27 mrem to endosteum (Table 4). Similar doses were calculated from eating beef from Church Rock. Consumption of ALG2 cattle resulted in radiation doses approximately twice those incurred from eating control cattle tissue. The dose incurred from eating Group 1 cattle for one year was associated with an even higher dose, especially to kidney (100 mrem above the control). Polonium-210 and Pb-210 were the most important nuclides in terms of dose to kidney, liver, and red marrow. Lead-210, followed by Ra-226 Po-210, and Th-230, contributed substantial fractions of the dose to endosteum. Because it is possible that the reported Po-210 measurements were higher than the true values, the dose contributions from Po-210 may be overestimates by a factor of about two.

Cancer risks associated with these doses for scenario 1 were one chance in 1,310,000 from ingesting control beef, one chance in 940,000 from eating Ambrosia Lake Group 2 cattle, one chance in 1,170,000 from Church Rock

cattle, and one chance in 280,000 from Ambrosia Lake Group 1 cattle. Continuous ingestion of Group 1 cattle for 20 years would incur a lifetime cancer risk of one chance in 14,000.

Eliminating liver and kidney from the diet and eating muscle tissue alone (scenario 2) reduces the internal radiation dose (Table 5). The dose from ingesting Ambrosia Lake Group 1 cattle, for example, is reduced by about 55%. The ingestion of Ambrosia Lake Group 2 or Church Rock cattle is associated with a negligible excess cancer risk. Consumption of beef from Ambrosia Lake Group 1 results in a cancer risk of one chance in 534,000.

The worst case estimates of scenario 3 predict much higher doses (Table 5). For instance, the resulting 50 year dose commitment to kidney from one year of ingestion was enhanced by a factor of 2.3, to 300 mrem. For one year of ingestion, corresponding cancer risk estimates are one chance in 120,000 for the highest exposure group (Ambrosia Lake Group 1) and one chance in 400,000 for Ambrosia Lake Group 2. The cancer risk for consuming Church Rock animals (one chance in 670,000) was similar to that from ingesting Crownpoint control cattle (one chance in 630,000) despite statistically higher uranium concentrations in tissues from Church Rock animals. This occurred since uranium contributed a small percentage of the total radiation dose.

The doses calculated for the various scenarios are based upon consumption of large amounts of muscle tissue, which contains lower radionuclide concentrations than liver or kidney. Eating liver and kidney incurs much higher internal radiation doses than eating muscle tissue. Since all of the dose and risk estimates are approximations, based upon numerous

assumptions concerning the uptake and retention of radionuclides and their cancer-causing potential at low doses, the actual doses and cancer risks may be higher or lower than the numbers we have presented. Although we calculated dose commitments according to estimates given by Dunning, other dose conversion factors which include higher and lower values than those of Dunning are reported in the literature (25). Furthermore, the fifty year dose commitments calculated in this report could underestimate the dose to potentially exposed children or infants since higher dose conversion factors are recommended for young age groups (26).

Interpretation and Significance of Elevated Radionuclide Levels in Exposed versus Control Cattle.

Despite the limitations of this investigation, the findings support the conclusion that the elevated radionuclide levels found in cattle tissues from Ambrosia Lake and Church Rock resulted from the cattle's exposures to radionuclide byproducts of the uranium mining and milling industry. The elevated tissue radioactivity in exposed compared to control cattle is confirmed by the statistical tests of significance and by the consistency of the data. Although the sample sizes in our study were small, the differences between exposed and control samples reached statistical significance for many of the radionuclides, and in most comparisons mean levels in all of the exposure groups exceeded those in controls. Thus, it is unlikely that the differences were due to chance. Since the cattle tissue was analyzed in a blind fashion by the laboratories, this reduced the possibility of bias in reporting results. The mean differences between radionuclide concentrations in exposed and control cattle, moreover, did

not result from high concentrations in a few isolated cattle. In Ambrosia Lake Group 1, 15 of the 24 comparisons to control animals were significant statistically. Radionuclide measurements in each each of the five cattle from Ambroisa Lake Group 1 exceeded mean levels of their respective controls in all but two of the 75 comparisons (Appendix Table B-1.). Further mean, radionuclide concentrations in the femurs of cattle from all three areas were numerically higher than controls in all but one of the 18 samples tested and the differences attained statistical significance in 10 of 18. This finding of high levels in bone tissue suggests that these animals were exposed chronically to U-238 chain radionuclides.

The environmental data collected in this investigation, although limited, strongly supports the conclusion that the elevated radionuclide levels in cattle tissue resulted from exposures to uranium mining and milling. Ambrosia Lake, the exposure area most impacted by the uranium mining and milling industry, had the highest concentrations of environmental radionuclides, and is the area in which cattle tissues contained the highest radionuclide levels. Animals from Ambrosia Lake were exposed to high ambient air radon, windblown tailings, and mine water. Church Rock, the exposure area farther removed from uranium mine operations had lower levels of environmental radionuclides compared to controls, and cattle tissue from this area had relatively lower radionuclide concentrations. The primary environmental source of radionuclides for these animals was mine water drunk by the cattle.

Data from this and other investigations provided evidence that the high radionuclide levels found in environmental samples were not due to natural sources of radiation. Natural background radioactivity was not measured

in Ambrosia Lake or Church Rock prior to start-up of the mining and milling operations. However, soil samples collected at Ambrosia Lake in another study indicated that true background concentrations were much lower than the radionuclide levels found in this investigation. In 1983 soils were collected at 16 locations across Ambrosia Lake from the surface and at a depth of 30 centimeters (cm) (10). The surface soil mean and standard error was 13.5 ± 6.6 pCi/gram for Ra-226, while soils collected at 30 cm depth averaged 0.57 ± 0.08 pCi/gram. Ra-226 concentrations in soil collected at 30 cm depth were similar to those collected at the surface at Crownpoint, NM. Therefore, the levels of Ra-226 in surface soil probably reflected contributions from the uranium mining and milling industry.

In the present study the grazing area for Ambrosia Lake Group 1 cattle has been flooded by mining effluent for years. Prior to 1979, when the ion exchange plant was built, the water that flooded this area was untreated uranium mine dewatering effluent. Soil from sample sites 11-13 contained extremely elevated levels of radionuclides, compared to the remaining samples. These sites were close to the discharge from the ion exchange plant but farther from the Phillips or other tailings piles than sample sites 10 and 14, which had much lower levels of soil radionuclides. In this case it appears that mine water rather than windblown tailings contributed more to high levels of U-238 chain radionuclides in grazing area 1.

The grazing area for Ambrosia Lake Group 2 cattle was not irrigated by uranium mine dewatering effluent. Soil containing the highest levels of U-238 chain radionuclides was from sampling sites 2, 4, and 5. These sites were very close to the Kerr-McGee tailings pile, and mine vents were

abundant in these areas. Radium-226 in soil from these sampling sites averaged 20.3 pCi/gram. Soil from sites 3, 6, and 7, which are farthest from the mill and its tailing pile, had levels of Ra-226 that averaged 1.3 pCi/gram. The elevated radionuclides in soil from grazing area 2 have therefore probably resulted from windblown tailings or radon daughters. These difference could not easily be attributed to variations in natural radioactivity.

The contribution of radon daughters to the radionuclide content of soil, vegetation, and cattle tissue is not clear. Radon gas is an important source of Pb-210 and Po-210, and ambient radon concentrations were elevated over background in Ambrosia Lake. Since radon is not a source of uranium, Th-230, or Ra-226, and since the soil, vegetation, and animal tissues contained relatively high levels of these radionuclides as well, it is evident that sources other than radon gas contributed significantly to the elevated radionuclide levels demonstrated in this investigation. Although cattle from Ambrosia Lake Group 1 had elevated levels of Po-210, cattle from Ambrosia Lake Group 2 were the only ones that had high levels of Pb-210 in any of the tissues, albeit only in kidney. It is possible that the elevated kidney Pb-210 levels resulted from exposure to radon gas and its daughter products.

In addition to the statistical significance, the consistency of this study's results, and evidence provided by environmental data, the conclusion of this investigation is also supported by previous research into cattle contamination by the uranium mining and milling industry. Holtzman et al. measured tissue concentrations of Ra-226, Pb-210 and Po-210 in two cows that foraged near the Anaconda uranium mill tailings pile

in New Mexico. Animals in this study had no access to uranium mine dewatering effluent (1). These cattle had muscle concentrations of 1.1 and 1.2 pCi/kg Ra-226, liver concentrations of 0.87 and 1.5 pCi/kg Ra-226, and kidney concentrations of 220 and 2.6 pCi/kg Ra-226. These Ra-226 levels and reported concentrations of Pb-210 (Appendix A, Table A-3) were generally intermediate between those found in Ambrosia Lake Group 1, Ambrosia Lake Group 2, and Church Rock cattle. Tissue concentrations of Po-210 were lower than those reported in the present study. The two control cattle in the Holtzman study had somewhat higher radionuclide concentrations than the averaged values for controls in this investigation.

Two cows collected from the Church Rock area in 1979 had muscle, liver, and kidney concentrations of U-238, U-234, Th-230, Ra-226, Pb-210, and Po-210, that were similar to the concentrations reported in the present analysis of Church Rock cattle (2). These cattle were from the same area as those in the present study. Another recent study examined ten sheep raised in Church Rock and ten controls. The findings of this investigation are presented elsewhere (27) but support the conclusion that radionuclide levels were higher than controls in sheep from Church Rock as well.

An additional objective of this investigation was to determine the risk to public health of eating exposed cattle over a long period of time. Owners of the purchased animals stated that they raise, slaughter, and consume their own animals. Further, it was assumed that some individuals buy a cow or a side of beef, freeze it, and consume it over several months. Thus, some New Mexican families might purchase an exposed animal and eat large quantities of meat containing elevated radionuclide concentrations.

To examine the importance of the elevated tissue radioactivity found in this study, we calculated estimates of internal radiation dose from ingesting exposed and control tissues. Dose estimates indicated that consumption of cattle tissue from Church Rock leads to approximately the same radiation dose as does eating control cattle. Consumption of Ambrosia Lake Group 2 cattle resulted in radiation doses approximately twice those incurred from control tissue consumption. Consuming cattle from Ambrosia Lake Group 1, however, is associated with a much higher dose estimate. After subtracting the dose estimated from ingestion of Crownpoint controls, which represents background doses for the area, the dose to human kidney from one year of ingestion exceeds 100 mrem. The general public, however, would not receive doses of this magnitude, as it is highly unlikely a person would consume a large amount of meat from one area of New Mexico. A person who buys and consumes 0.5 kg of muscle from Ambrosia Lake group 1 cattle, for example, would receive a 50 year dose commitment of 0.87 mrem to the kidney, compared with a dose of 0.17 mrem from eating this much control beef.

For all the assumed scenarios, cancer risks attributable to eating beef from each of the exposure groups were within the ICRP's acceptable limit of below one excess death per 100,000 individuals in a population (22). These calculations were based on the assumption that a person eats 78 kg of area beef for one year. It is probable that few residents are exposed to this extent. For those who have eaten area meat, especially liver and kidney, for a prolonged period of time, risk estimates may exceed the acceptable limit. The 20 year ingestion risk estimate for Ambrosia Lake Group 1, scenario 1, for example, is one death per 14,000 exposed individuals.

To place this risk in perspective, it has been estimated by the EPA that individuals living continuously next to some uranium mill tailings piles may have an excess lifetime lung cancer risk as high as 4 chances in a hundred (28). This risk is from exposure to radon decay products emitted directly from the tailings pile. If a person ingests Ambrosia Lake Group 1 beef (scenario 1) for 60 years but is not exposed to the uranium mining and milling industry in any other way, his lifetime risk of a cancer death, primarily from cancer of the kidney, liver, and bone, would be about one death in 4500.

EPA standards and New Mexico EID regulations limit the organ doses to individuals to 25 mrem per year, but currently exempt radiation exposures from uranium mine effluents, and from radon and its daughters, which include Pb-210 and Po-210 (8, 11). Doses incurred from ingesting Ambrosia Lake Group 1 cattle for one year exceeded the 25 mrem/yr limit. Lead-210 and Po-210 were identified as the major dose contributors following consumption of these tissues from cattle exposed most heavily to uranium mine effluents. Therefore, it may not be appropriate to exempt either radon daughters or uranium mine effluents from present standards and regulations.

Current regulations are based on the assumption that the source of the exposure is known. However, the present investigation did not determine whether the source of radioactivity was mill tailings, mine dewatering effluent, or the inhalation and/or ingestion of radon and its daughters.

The most highly contaminated animals were exposed to all of these sources. Further environmental sampling and measurements of tissue radionuclide concentrations in animals exposed only to dewatering effluents, or to mill tailings, are needed to identify the relative contribution from each source. Until these studies are completed, restricting access of livestock to uranium mine dewatering effluent, and restricting grazing of animals on land that has been irrigated with mine water or is in proximity to mill tailings, would markedly reduce the probability of food chain contamination.

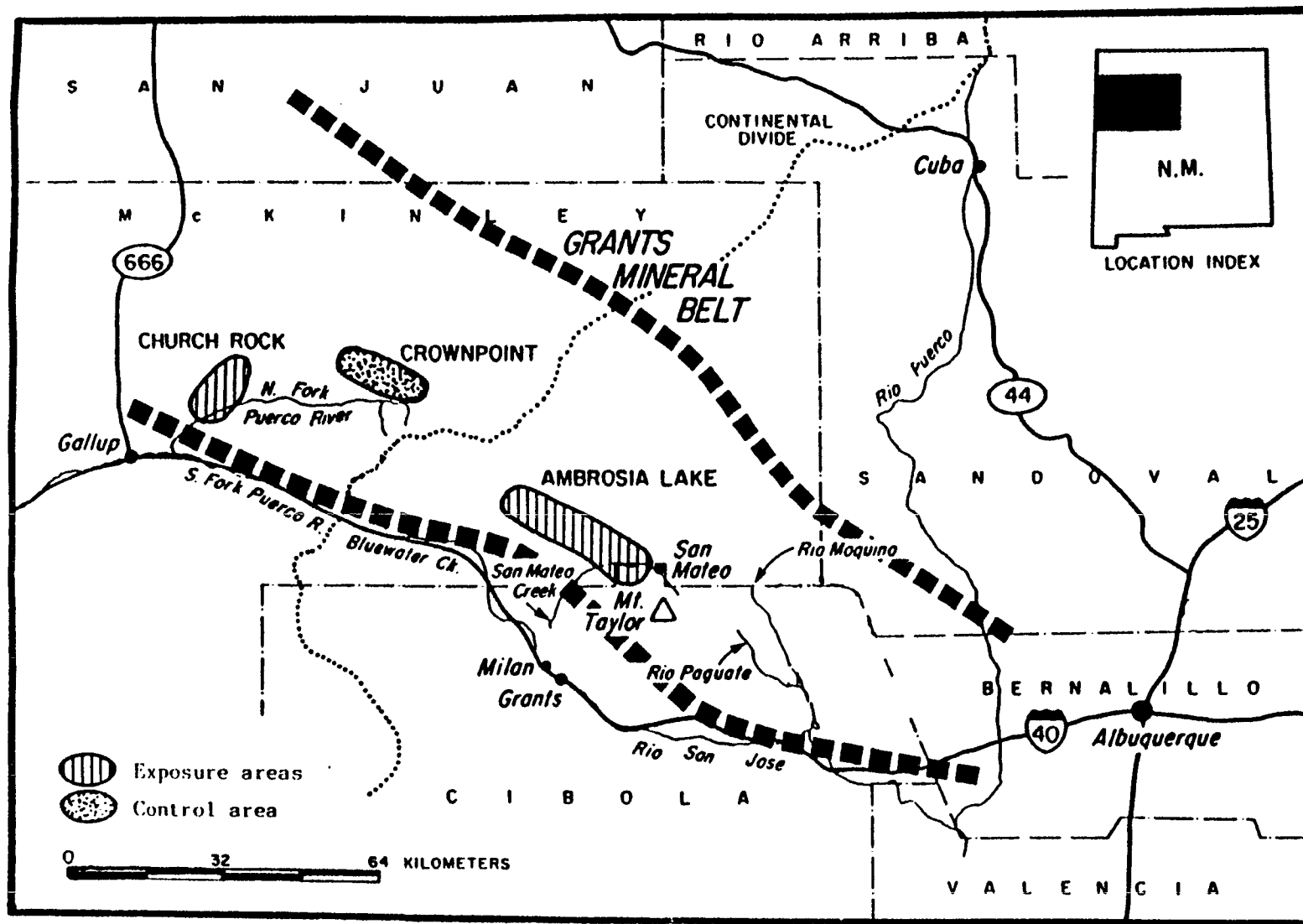


Figure 1. Grant's Mineral Belt, New Mexico.

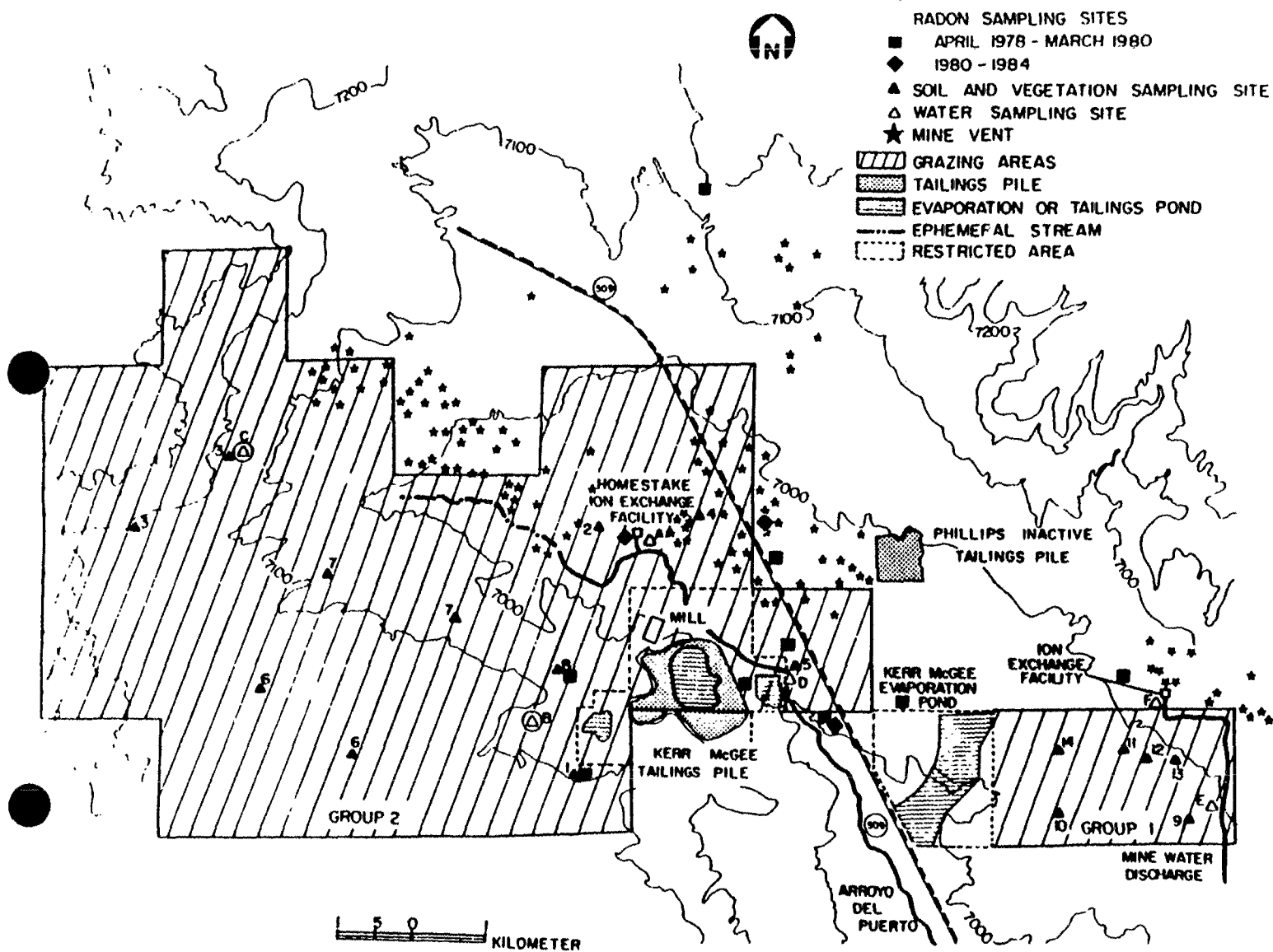


Figure 2. Cattle grazing areas and environmental sampling sites, Ambrosia Lake, New Mexico.

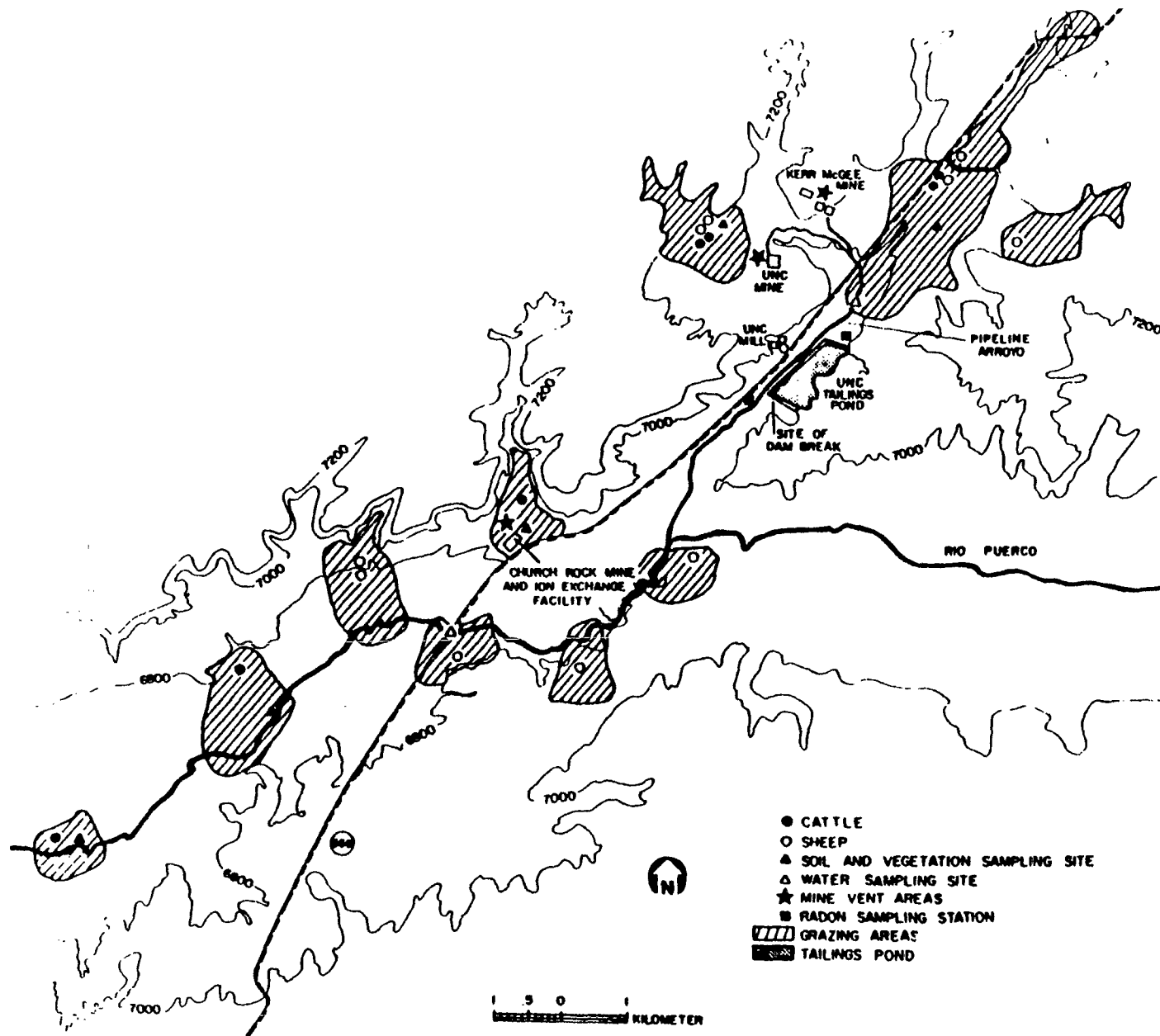


Figure 3. Cattle grazing areas and environmental sampling sites, Church Rock, New Mexico.

TABLE 1. Approximate sample weights and lower limits of detection (LLD) for radionuclide analysis of cattle tissue, vegetation, soil, and water.

Radionuclide	Liver, Muscle		Kidney		Bone	
	wet. wt. (g)	LLD (pCi/kg)	Wet wt. (g)	LLD (pCi/kg)	Wet. Wt. (g)	LLD (pCi/kg)
U-234, U-238	200	0.2	40	1.0	50	0.8
Th-230	200	0.2	40	1.0	50	0.8
Ra-226	100	0.2	20	1.0	100	0.2
Pb-210	500	1.0	200	2.5	200	2.5
Po-210	500	1.0	200	2.5	200	2.5

Radionuclide	Vegetation		Soil		Water	
	dry wt. (g)	LLD (pCi/gm)	dry wt. (g)	LLD(pCi/gm)	wet wt. (l)	LLD (pCi/l)
U-234, U-238	5	0.01	4	0.01	0.5	0.1
Th-230	5	0.01	4	0.01	0.5	0.1
Ra-226	5	0.01	1	0.01	0.1	0.1
Pb-210	20	0.05	10	0.10	1	1.0
Po-210	20	0.01	10	0.01	1	0.1

TABLE 2. Mean radionuclide concentrations in edible tissues and femurs from exposed and control cattle.

Exposure	Radionuclide Concentration (pCi/kg wet wt. \pm standard error of the mean)					
Group	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
Ambrosia Lake Group 1 (n=5)						
Muscle	0.8 \pm 0.2	0.8 \pm 0.3	0.7 \pm 0.2	4.0 \pm 1.6 ^{ac}	2.2 \pm 1.1	92 \pm 15 ^{ac}
Liver	5.2 \pm 0.6 ^{ac}	5.3 \pm 0.5 ^{ac}	4.7 \pm 2.1 ^b	12.4 \pm 4.5 ^{ac}	91 \pm 87	1521 \pm 458 ^{ac}
Kidney	11.0 \pm 1.9 ^{ac}	11.2 \pm 2.1 ^{ac}	16.3 \pm 5.7 ^{ab}	117 \pm 43 ^{ac}	79 \pm 23	1770 \pm 502 ^{ab}
Femur	87 \pm 25 ^b	94 \pm 30 ^b	10 \pm 5.4 ^a	7100 \pm 2119 ^{ac}	1132 \pm 244	1436 \pm 1359
Ambrosia Lake Group 2 (n=5)						
Muscle	0.5 \pm 0.2	0.8 \pm 0.2	0.26 \pm 0.04	0.2 \pm 0.4	2.1 \pm 0.9	8.3 \pm 3.6
Liver	1.8 \pm 0.9 ^b	1.6 \pm 0.7 ^b	1.1 \pm 0.2	0.3 \pm 0.3	10.2 \pm 7.3	334 \pm 124
Kidney	7.0 \pm 2.5 ^{ac}	7.2 \pm 2.7 ^{ab}	5.0 \pm 1.0 ^b	23 \pm 9 ^b	345 \pm 141 ^a	847 \pm 189
Femur	166 \pm 78 ^{ab}	175 \pm 70 ^{ac}	5.4 \pm 3.4	3860 \pm 1078 ^{ac}	952 \pm 361	2353 \pm 1831
Church Rock (n=7)						
Muscle	1.4 \pm 0.5	1.9 \pm 0.4 ^a	0.9 \pm 0.4	0.8 \pm 0.2	0.4 \pm 0.7	16.8 \pm 3.8
Liver	1.4 \pm 0.4 ^b	1.9 \pm 0.5 ^{ab}	3.5 \pm 1.4	0.3 \pm 0.2	1.0 \pm 0.7	175 \pm 53
Kidney	2.6 \pm 0.6	2.9 \pm 0.6	5.8 \pm 1.8	8.9 \pm 3.1	84 \pm 19	818 \pm 201
Femur	101 \pm 39 ^b	100 \pm 38 ^b	1.6 \pm 0.5	2690 \pm 1258 ^b	771 \pm 310	2192 \pm 995
Crownpoint Control (n=10)						
Muscle	0.7 \pm 0.2	0.8 \pm 0.1	0.4 \pm 0.1	0.3 \pm 0.2	2.4 \pm 1.5	14.0 \pm 3.4
Liver	0.4 \pm 0.1	0.4 \pm 0.1	1.6 \pm 1.3	0.3 \pm 0.2	6.8 \pm 3.8	249 \pm 56
Kidney	1.3 \pm 0.3	1.5 \pm 0.5	2.3 \pm 0.8	4.6 \pm 1.8	81 \pm 15	455 \pm 147
Femur	6.6 \pm 4.0	7.1 \pm 2.6	2.3 \pm 1.0	152 \pm 52	411 \pm 74	288 \pm 187

^a Significantly ($p < .05$) higher than Crownpoint control, analysis of variance, Duncan's multiple range test

^b Significantly ($p < .05$) higher than Crownpoint control, Wilcoxon's two-sample test

^c Significantly ($p < .003$) higher than Crownpoint control, Wilcoxon's two-sample test

TABLE 3.

Mean radionuclide concentrations in vegetation, soil, and water.

Exposure Group	Type of Sample (n)	Radionuclide Concentration (pCi/gm dry wt; water, pCi/l \pm standard error of the mean)					
		U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
Ambrosia Lake Group 1	Vegetation (5)	1.5 \pm 1.0	1.6 \pm 1.1	0.9 \pm 0.3 ^b	3.4 \pm 1.5 ^b	0.6 \pm 0.1	3.4 \pm 1.3
	Soil (6)	30 \pm 20 ^b	34 \pm 22 ^b	115 \pm 63 ^{ab}	514 \pm 311 ^a	590 \pm 437 ^b	398 \pm 224 ^{ab}
	Water (2)	670 \pm 20 ^a	770 \pm 10 ^a	0.2 \pm 0.05	2.0 \pm 0	7.0 \pm 3.0	16 \pm 12
Ambrosia Lake Group 2	Vegetation (8)	1.1 \pm 0.5	1.0 \pm 0.5	3.4 \pm 1.9 ^b	1.7 \pm 0.8 ^b	5.0 \pm 2.5	3.0 \pm 1.3
	Soil (8)	4.0 \pm 1.9	4.5 \pm 2.3	15 \pm 9	8.4 \pm 4.2	13 \pm 6	1.8 \pm 0.8
	Water (4)	79 \pm 74	77 \pm 71	1.2 \pm 0.7	1.4 \pm 0.9	6.5 \pm 1.5	17 \pm 11
Church Rock	Vegetation (5)	0.3 \pm 0.2	0.3 \pm 0.2	0.22 \pm 0.008	2.0 \pm 1.5	0.5 \pm 0.3	2.7 \pm 2.1
	Soil (5)	1.7 \pm 0.6	1.8 \pm 0.6	2.9 \pm 0.9	2.9 \pm 1.2	4.1 \pm 1.5	4.1 \pm 1.5
	Water (2)	515 \pm 75 ^a	530 \pm 60 ^a	0.7 \pm 0.1	0.9 \pm 0.2	2.5 \pm 0.5	0.8 \pm 0.6
Crownpoint Control	Vegetation (4)	0.2 \pm 0.06	0.2 \pm 0.05	.05 \pm 0.03	0.08 \pm 0.03	1.0 \pm 0.1	0.4 \pm 0.2
	Soil (4)	0.8 \pm 0.1	0.7 \pm 0.1	0.9 \pm 0.2	0.8 \pm 0.1	2.3 \pm 0.6	1.9 \pm 0.4
	Water (2)	0.9 \pm 0.6	1.0 \pm 0.5	0.2 \pm 0.1	2.3 \pm 0.7	5.0 \pm 0	2.0 \pm 2.0

^a Significantly ($p < .05$) higher than Crownpoint control, analysis of variance, Duncan's multiple range test^b Significantly ($p < .05$) higher than Crownpoint control, Wilcoxon's two-sample test

TABLE 4. Dose to human target organs from ingestion of cattle tissue assuming Scenario 1^a conditions.

Target Organs (50 year dose commitments in mrem, per year of ingestion)					
Exposure Group I	Nuclide	Kidney	Liver	Endosteum	Red Marrow
<hr/>					
Ambrosia Lake Group 1	U-238	.131	.00071	.305	.020
	U-234	.152	.00076	.355	.023
	Th-230	.00021	.0019	1.12	.086
	Ra-226	.160	.160	12.12	1.07
	Pb-210	5.06	11.65	40.51	2.79
	Po-210	<u>123.8</u>	<u>21.07</u>	<u>3.95</u>	<u>3.95</u>
	Total	129	33	58	7.9
<hr/>					
Ambrosia Lake Group 2	U-238	.081	.00046	.196	.013
	U-234	.129	.00070	.311	.019
	Th-230	.00008	.00063	.370	.029
	Ra-226	.015	.016	1.20	.106
	Pb-210	6.41	14.74	51.29	3.53
	Po-210	<u>24.68</u>	<u>4.20</u>	<u>.784</u>	<u>.788</u>
	Total	31	19	54	4.5
<hr/>					
Church Rock	U-238	.166	.00094	.401	.027
	U-234	.260	.0014	.624	.039
	Th-230	.00021	.0019	1.10	.084
	Ra-226	.024	.024	1.79	.158
	Pb-210	1.43	3.30	11.46	.788
	Po-210	<u>26.25</u>	<u>4.47</u>	<u>.837</u>	<u>.837</u>
	Total	28	7.8	16	1.9
<hr/>					
Crownpoint Control	U-238	.079	.00044	.188	.013
	U-234	.104	.00057	.249	.016
	Th-230	.00010	.00087	.510	.039
	Ra-226	.009	.0092	.661	.059
	Pb-210	3.06	7.03	24.45	1.68
	Po-210	<u>21.61</u>	<u>3.68</u>	<u>.690</u>	<u>.690</u>
	Total	25	11	27	2.5

^a Scenario 1 assumes an annual ingestion of 74 kg muscle, 2.7 kg liver, and 1.3 kg kidney.

TABLE 5 Dose to human target organs from ingestion of cattle tissue
assuming Scenario 2 and 3 conditions.

Scenario 2	Location	Target Organs (50 year dose commitments in mrem per year of ingestion)			
		Kidney	Liver	Endosteum	Red Marrow
	Ambrosia Lake Group 1	69.3	15.5	24.5	3.9
	Ambrosia Lake Group 2	7.9	4.8	14.4	1.2
	Church Rock	13.1	2.8	6.3	0.8
	Crownpoint Control	12.4	6.1	16.9	1.5

Scenario 3	Location	Target Organs (50 year dose commitments in mrem per year of ingestion)			
		Kidney	Liver	Endosteum	Red Marrow
	Ambrosia Lake Group 1	300	84.0	153	19.0
	Ambrosia Lake Group 2	78.6	38.1	98.2	8.8
	Church Rock	54.4	14.7	26.6	3.4
	Crownpoint Control	54.7	18.9	39.7	4.2

- a This scenario assumes an annual ingestion of 78 kg of muscle (no liver or kidney).
- b This scenario assumes an annual ingestion of 62.3 kg muscle, 13.1 kg liver, 2.6 kg kidney.

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APPENDIX A.

Quality Control Comparisons.

Split samples of muscle, liver, and kidney from six cattle were analyzed for each radionuclide by both laboratories. Eleven analyses were not completed by EPA-Las Vegas due to technical problems. Thus, 97 pairs of split sample results were compared. A range, consisting of the reported radionuclide concentration \pm the counting error, was calculated. The ranges overlapped for 56 (58%) of the pairs. For statistical comparison, paired results were grouped by radionuclide and analyzed (Table A-1) using a two-tailed, paired-sample t-test (1).

Differences between polonium-210 values reported by the two laboratories were significant statistically. Mean polonium values reported by Eberline for muscle, liver, and kidney were 1.7, 2.4, and 1.7 times higher, respectively, than those reported by EPA-Las Vegas (Table A-2). None of the paired-sample t-tests for the remaining radionuclides were significant statistically at the $p < 0.05$ level of significance.

Since Po-210 is the radionuclide that contributed most to the internal dose received from eating cattle, this discrepancy between the two laboratories is of concern. Eberline Laboratory reported consistently higher values for Po-210, although the methods used by both laboratories in determining Po-210 activity were the same. Both laboratories, moreover, analyzed the tissues for Po-210 several months after the samples were collected. Thus, laboratory delays in performing Po-210 analyses may have contributed to

errors in Po-210 measurements. Po-210 has a short half life (138 days) (2). Both laboratories separated the muscle for Pb-210 and Po-210, 110 days, almost one half life, after the animals were sacrificed. Eberline performed the analyses on liver samples 318, and in one sample 354, days after collection, and on kidney samples 195 or 200 days post collection. EPA-Las Vegas analyzed liver and kidney 129 and 101 days after collection, respectively. Although the Po-210 concentrations were corrected for ingrowth from Pb-210 and for Po-210 decay, performance of laboratory analyses several half-lives after sample collection and mathematical correction of the concentrations to the separation date could introduce error into the results when there is low specific activity in the tissues.

In order to evaluate the differences noted between Po-210 measurements by the two laboratories, we compared Po-210/Pb-210 ratios reported in this investigation with Po-210/Pb-210 ratios reported for femurs and soft tissues elsewhere in the literature. Po-210/Pb-210 ratios in human bone have been reported to approximate 1.0 (3). However, reported Po-210/Pb-210 ratios in animal femurs have not been found to equal one consistently. In two previous reports, Po-210/Pb-210 ratios in animal femurs ranged from 0.84 to 23.8 (Table A-3). Average Po-210/Pb-210 ratios in femurs reported by Eberline Laboratory in the present study were from 1.3 to 15.1 in cattle from the three exposed groups and 0.8 among femurs from control cattle (Table A-4). In some cases, these averages are small numbers primarily because of very low corrected Po-210 concentrations. For example, 6 of 10 individual measurements in control femurs had corrected Po-210 values of zero (Appendix B). EPA-Las Vegas did not perform radiochemical analyses of bone in the present study.

It has been suggested by Osborne that Po-210 may be concentrated in the soft tissues, particularly liver and kidney, of humans and animals, the Po-210 being measurably in excess of Pb-210 (2). He reported Po-210/Pb-210 ratios for the human liver and kidney of 1.8 to 8.9 (Table A-3). Polonium-210/Pb-210 ratios reported for livers and kidneys of cattle raised in a rural area averaged 2.6 and 4.1 respectively (5), while ratios in cattle, sheep, and goats exposed to products of the uranium mining and milling industry in previous reports (4, 6) ranged from 0.2-26 in liver and 0.65-8.95 in kidney (Table A-3). Most of the averaged Po-210/Pb-210 ratios for muscle, liver, and kidney calculated from values reported by Eberline Laboratory were much higher values than those reported previously and were also higher than those reported by EPA-Las Vegas (Table A-4). This casts doubt on the accuracy of either the Pb-210 or the Po-210 measurements performed by Eberline Laboratory.

The Po-210 concentrations reported by Eberline Laboratory for the exposed and control cattle were higher, both when compared to EPA-Las Vegas' measurements and when compared to other published reports. Thus, it is probable that the Po-210 measurements were in error. Eberline Laboratory's reported values were approximately twice those of EPA-Las Vegas. Thus, the true values for Po-210 may have been half those reported in Table 2.

TABLE A-1. Differences between radionuclide concentrations reported by two laboratories for split samples of muscle, liver, and kidney tissue.

Radionuclide	(N)	Mean Difference ^a	SEM ^b	t value	t value required for statistical significance t 0.05(2), df=N-1
U-238	(16)	-0.9	0.71	-1.27	+2.13
U-234	(16)	-0.53	0.77	-0.69	+2.13
Th-230	(16)	1.5	1.09	1.38	+2.13
Ra-226	(18)	-7.54	5.11	-1.48	+2.11
Pb-210	(15)	6.49	18.63	0.32	+2.145
o-210	(16)	89.8	32.7	2.7 ^d	+2.13

^a Mean difference =
$$\frac{(\text{Eberline's reported value} - \text{EPA-Las Vegas' reported value})}{N}$$

^b Standard error of the mean

^c $t = \frac{\text{mean difference}}{\text{SEM}}$

^d Significant at $p < 0.02$

TABLE A-2. Mean radionuclide concentrations reported by two laboratories for split samples of muscle, liver, and kidney.

Mean Radionuclide Concentrations \pm SEM (pCi/kg wet wt) ^a							
Laboratory	Tissue	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210(b)
Cherline	Muscle	0.53 \pm 0.09(6) ^c	0.92 \pm .17(6)	0.57 \pm 0.20(6)	2.4 \pm 1.5(6)	1.5 \pm 0.8(5)	15 \pm 8(6)
EPA-Las Vegas		0.23 \pm 0.06(6)	0.21 \pm .05(6)	0.34 \pm 0.11(6)	2.6 \pm 1.8(6)	2.4 \pm 0.2(5)	8.7 \pm 3.5(6)
Cherline	Liver	1.2 \pm 0.8(4)	1.4 \pm 0.9(4)	2.8 \pm 1.8(4)	6.2 \pm 4.1(6)	88 \pm 88(5)	159 \pm 65(4)
EPA-Las Vegas		1.7 \pm 1.1(4)	1.8 \pm 1.3(4)	1.1 \pm 0.8(4)	13.2 \pm 9.5(6)	66 \pm 38(5)	67 \pm 42(4)
Cherline	Kidney	4.4 \pm 2.0(6)	5.3 \pm 2.3(6)	8.2 \pm 2.6(6)	33 \pm 20(6)	62 \pm 14(5)	408 \pm 108(6)
EPA-Las Vegas		6.0 \pm 3.6(6)	7.1 \pm 3.9(6)	7.7 \pm 3.8(6)	49 \pm 33(6)	63 \pm 19(5)	235 \pm 80(6)

^aStandard error of the mean

Cherline's Po-210 reported values were corrected for radioactive decay and for the ingrowth from Pb-210, to EPA-Las Vegas' (earlier) separation date.

^c() indicates the number of samples within each mean

Tissue Type	Animal	Pb-210 Concentration (pci/kg)	Pb-210 Concentration (pci/kg)	Pb-210/Pb-210 Ratio	Author	Reference
Vertebra	Human	17 average of 9 samples	7000	0.43	Osborne	3
Liver	Human	10 (average of 4 samples)	3550	1.8		
Kidney	Human	7.1 (average of 2 samples)	2020	9.9		
				4.1		
<hr/>						
Farm	Cattle	Cow 1 5600 Cow 2 -	7000 3080	0.94	Holtzman et al.	4
Control		Cow 3 8130 (pci/kg ash) Cow 4 1700 (pci/kg ash)	3550 (pci/kg ash) 2020 (pci/kg ash)	2.35 0.94		
Muscle	Exposed ^a	Cow 1 36 Cow 2 60	9.5 1.8	3.79 33.3		
Control		Cow 3 80 Cow 4 330	28 2.6	2.86 126.92		
Liver	Exposed ^a	Cow 1 230 Cow 2 340 Cow 3 - Cow 4 -	209 73 31 12	1.10 4.66 -		
Kidney	Exposed ^a	Cow 1 685 Cow 2 270 Cow 3 1800 Cow 4 -	420 41 260 330	1.63 6.59 6.92 -		
<hr/>						
Liver	Cattle			2.58	Bunzel et al.	5
<hr/>						
Kidney	Cattle			4.13 average for 32 cattle not exposed to traffic or industry (range 1.1-9.1)		
<hr/>						
Farm	Cattle	300	72	4.17	Ruttenber et al.	6
Exposed ^b Sheep		1000	230	4.35		
Control-1		1800	870	2.07		
Control-2		780	32	23.75		
Exposed ^b Goat		480	150	3.20		
Muscle	Exposed ^b Sheep	12	4.1	2.93		
Liver	Exposed ^b Sheep	11	26	.42		
Control-1	Exposed ^b Cow	56	5.4	10.37		
Control-2	Exposed ^b Cow	130	44	2.95		
Exposed ^b Sheep		29	1.1	26.36		
Control-1	Exposed ^b Sheep	25	7.6	3.29		
Control-2	Exposed ^b Sheep	50	290	0.17		
Exposed ^b Sheep		29	43	0.67		
Control-1	Exposed ^b Sheep	17	28	0.65		
Control-2	Exposed ^b Sheep	72	210	0.34		
Kidney	Exposed ^b Cow	260	56	4.64		
Control	Exposed ^b Cow	650	130	5.0		
Exposed ^b Sheep		160	44	3.64		
Control-1	Exposed ^b Sheep	460	710	0.65		
Control-2	Exposed ^b Sheep	150	28	5.36		
Exposed ^b Sheep		220	72	3.06		
Control-1	Exposed ^b Sheep	200	80	2.50		
Control-2	Exposed ^b Sheep	170	19	8.95		
Exposed ^b Goat		540	470	1.15		

^a Exposed cattle grazed near Maricopa mill in New Mexico
^b Exposed cattle were from Church Rock, New Mexico

TABLE A-4. Po-210 to Pb-210 ratios in muscle, liver, and kidney tissue reported by two laboratories.

	<u>Eberline^a</u>		<u>EPA-Las Vegas^b</u>
Ambrosia Lake Group 1	Muscle	58	6.5, 7.2
	Liver	641	2.6 -
	Kidney	29.5	6, 4.3
	Femur	1.3	
Ambrosia Lake Group 2	Muscle	11.8	
	Liver	247	
	Kidney	5.3	
	Femur	15.1	
Church Rock	Muscle	54.2	1.0 -
	Liver	220	2.2 -
	Kidney	16.5	3.4, 4.6
	Femur	4.8	
Crownpoint	Muscle	13.5	1.3, 1.4
	Liver	190	- 1.2
	Kidney	9.8	- 2.2
	Femur	0.8	

^aDetermined by averaging the individual Po-210/Pb-210 ratios for tissues from each animal. All negative and zero numbers for Po-210 or Pb-210 concentrations were set to equal one.

^bIndividual determinations

REFERENCES FOR APPENDIX A

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3. R. B. Holtzman, "Measurement of the natural contents of RaD (Pb-210) and RaF (Po-210) in human bone-estimates of whole body burdens," Health Phys. 9,385 (1963).
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Figure 1

[illegible]

Prefix letter:

Letter following each radionuclide:

M=Individual measurement in picocuries per kilogram wet weight
F=counting error, (2 standard deviations)

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LOC = (rowpoint

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LOC=Ambrosia Lake Group 1

IDS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	P0210M	P0210E	VOL_MET
1	M05	W	110483	780.0	20.0	690.0	20.0	0.2	0.1	2.0	1.0	4.0	1.0	28.4	3.1	3790
2	M06	W	110483	760.0	20.0	650.0	20.0	0.1	0.1	2.0	1.0	10.0	2.0	4.5	1.2	3790
3	S09	S	110483	2.0	0.2	1.8	0.2	1.8	0.1	0.7	0.2	4.4	0.4	5.6	0.8	1265
4	S10	S	110483	9.3	0.5	7.6	0.4	2.8	0.3	13.0	4.0	8.0	0.5	5.8	1.1	787
5	S11	S	110483	26.0	2.0	21.0	2.0	100.0	10.0	170.0	50.0	110.0	10.0	170.0	30.0	834
6	S12	S	110483	27.0	1.0	21.0	1.0	190.0	20.0	1100.0	300.0	710.0	70.0	1143.0	153.0	448
7	S13	S	110483	140.0	10.0	130.0	10.0	390.0	40.0	1800.0	500.0	2700.0	300.0	1058.0	333.0	401
8	S14	S	110983	0.9	0.1	1.0	0.1	4.1	0.1	1.1	0.3	6.2	0.4	3.1	0.6	985
9	V09	V	110483	0.3	0.1	0.3	0.0	1.1	0.1	0.3	0.1	0.6	0.2	0.6	0.2	290
10	V10	V	110483	0.6	0.1	0.5	0.1	1.5	0.2	2.0	1.0	0.2	0.1	3.5	0.4	123
11	V11	V	110483	0.9	0.1	0.9	0.1	1.0	0.1	8.0	2.0	0.6	0.2	8.3	1.7	129
12	V12	V	110483	5.9	0.3	5.6	0.3	0.6	0.1	6.0	2.0	0.6	0.2	3.1	0.4	222
13	V13	V	110983	0.3	0.1	0.3	0.1	1.5	0.1	0.9	0.3	1.1	0.3	1.3	0.3	67

LOC=Ambrosia Lake Group 2

IDS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	P0210M	P0210E	VOL_MET
14	M01	W	110983	290.0	20.0	300.0	20.0	0.2	0.1	-0.1	0.1	8.0	1.0	0.0	0.5	3360
15	M02	W	111083	16.0	3.0	13.0	3.0	0.2	0.2	0.6	0.2	4.0	1.0	0.0	0.5	3730
16	M03	W	111083	0.2	0.2	0.9	0.2	1.4	0.3	1.3	0.4	10.0	2.0	24.8	3.1	3690
17	M04	W	111083	0.2	0.2	0.1	0.2	3.0	1.0	4.0	1.0	4.0	1.0	43.9	4.5	3670
18	S01	S	111083	0.6	0.1	0.6	0.1	0.8	0.1	1.1	0.3	2.6	0.3	2.3	0.3	1084
19	S02	S	110983	19.0	1.0	16.0	1.0	60.0	2.0	32.0	3.0	40.0	4.0	6.5	3.4	734
20	S03	S	111083	2.6	0.1	2.6	0.1	1.8	0.1	2.0	1.0	1.8	0.3	1.1	0.2	1518
21	S04	S	110983	9.4	0.7	7.7	0.7	4.7	0.2	8.0	2.0	10.0	1.0	0.0	0.5	946
22	S05	S	111083	2.6	0.2	2.8	0.2	46.0	5.0	21.0	6.0	43.0	4.0	0.3	2.1	930
23	S06	S	111083	0.5	0.1	0.5	0.1	0.9	0.2	0.8	0.2	1.7	0.3	0.3	0.2	1791
24	S07	S	111083	0.6	0.1	0.6	0.1	0.7	0.2	1.0	0.3	3.2	0.3	0.0	0.2	1351
25	S08	S	110983	1.0	0.2	1.1	0.2	1.2	0.2	1.4	0.4	3.0	0.3	0.0	0.6	1018
26	V01	V	111083	0.3	0.0	0.2	0.0	0.2	0.1	0.2	0.1	1.5	0.1	8.0	0.2	101
27	V02	V	111083	0.2	0.0	0.3	0.0	0.1	0.0	0.2	0.0	1.5	0.4	0.0	0.3	184
28	V03	V	110983	1.5	0.2	2.3	0.2	4.8	0.6	6.0	2.0	6.0	1.0	4.3	1.8	87
29	V04	V	111083	0.3	0.1	0.3	0.1	0.2	0.1	0.3	0.1	2.3	0.2	0.1	0.2	148
30	V05	V	110983	4.3	0.5	3.9	0.5	4.7	0.6	2.0	1.0	4.0	1.0	5.7	1.8	81
31	V06	V	111083	0.9	0.1	0.7	0.1	16.0	1.0	4.0	1.0	22.0	5.0	10.1	4.9	163
32	V07	V	111083	0.2	0.1	0.2	0.1	0.3	0.2	0.1	0.1	2.0	0.2	1.0	0.2	158
33	V08	V	110983	0.5	0.1	0.6	0.1	0.5	0.1	0.7	0.2	0.6	0.1	2.7	0.4	110

LOC=Crownpoint

IDS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	P0210M	P0210E	VOL_MET
34	M09	W	110383	1.5	0.3	1.5	0.3	0.3	0.1	3.0	1.0	5.0	1.0	0.0	0.5	2930
35	M10	W	110383	0.5	0.2	0.3	0.1	0.1	0.1	1.6	0.5	5.0	1.0	3.9	0.8	3870
36	S15	S	110383	0.5	0.1	0.5	0.1	0.7	0.1	0.8	0.2	1.5	0.3	1.5	0.3	1388
37	S16	S	110383	0.8	0.1	0.9	0.1	0.9	0.2	0.6	0.2	4.1	0.4	1.1	0.4	901
38	S17	S	110383	0.8	0.1	0.9	0.1	0.7	0.1	0.7	0.2	1.5	0.3	2.8	0.3	982
39	S18	S	110383	0.7	0.1	0.8	0.1	1.4	0.1	1.1	0.3	2.1	0.3	2.3	0.3	1360
40	V14	V	110383	0.2	0.0	0.1	0.0	0.0	0.0	1.1	0.0	0.8	0.3	0.3	0.3	82
41	V15	V	110383	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.9	0.1	0.2	0.2	103
42	V16	V	110383	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	1.0	0.2	1.0	0.2	93

LOC=Crowpoint

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
43	V17	V	110383	0.3	0.1	0.3	0.1	0.1	0	0.1	0	1.2	0.1	0.1	0.2	96

LOC=Church Rock

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
44	W07	W	120183	470.0	20.0	440.0	20.0	0.7	0.3	1.0	0.3	3.0	1.0	0.2	0.4	3410
45	W08	W	120183	590.0	20.0	590.0	20.0	0.6	0.2	0.7	0.2	2.0	1.0	1.3	0.4	4170
46	S19	S	111883	0.6	0.1	0.6	0.1	0.7	0.1	1.1	0.3	1.2	0.3	2.0	0.3	1175
47	S20	S	111883	1.1	0.1	1.1	0.1	4.2	0.2	1.5	0.5	2.3	0.3	2.1	0.4	813
48	S21	S	111883	2.4	0.4	2.4	0.4	4.0	0.2	4.0	1.0	6.5	0.4	7.1	0.9	722
49	S22	S	111883	0.9	0.1	1.0	0.1	0.9	0.2	1.0	0.3	1.8	0.3	1.0	0.2	1053
50	S23	S	111883	3.8	0.2	3.6	0.2	4.8	0.2	7.0	2.0	8.6	0.5	8.5	1.3	901
51	V18	V	111883	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.2	0.1	11.0	0.2	180
52	V19	V	111883	0.1	0.0	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.6	0.2	91
53	V20	V	111883	0.3	0.1	0.3	0.0	0.3	0.0	8.0	2.0	1.5	0.6	0.0	0.4	178
54	V21	V	111883	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.2	0.1	0.9	0.2	96
55	V22	V	111883	0.9	0.1	0.9	0.1	0.5	0.0	1.7	0.5	0.7	0.3	0.9	0.2	116

Type:

W=water

S=soil

V=vegetation

Letter following each radionuclide:

M=individual measurement in pCi/kg dry wt. for soil and vegetation, wet wt. for water

E=counting error (2 standard deviations)

REFERENCE #7

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT #

Meeting: (X)

Telephone: ()

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

AND TITLE : Patrick Antonio, Hydrogeologist, NSO

PHONE: 602-871-7331

FROM (Contacting

Party) : T. Morris, Environmental Spec., NSO

DATE : 6/18/90

SUBJECT: "Sole Source" aquifer, Flood Plain, Haystack Mountain, NM

CONTACT SUMMARY REPORT:

There is no "Sole Source" aquifer, and The Nanabah Vandever site is not in a flood plain.

REFERENCE #8

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT #

Meeting: (X)

Telephone: ()

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED
AND TITLE : Pat Molloy, Health Physicist, NSO

PHONE: 602-871-7332

FROM (Contacting
Party) : T. Morris, Environmental Spec., NSO

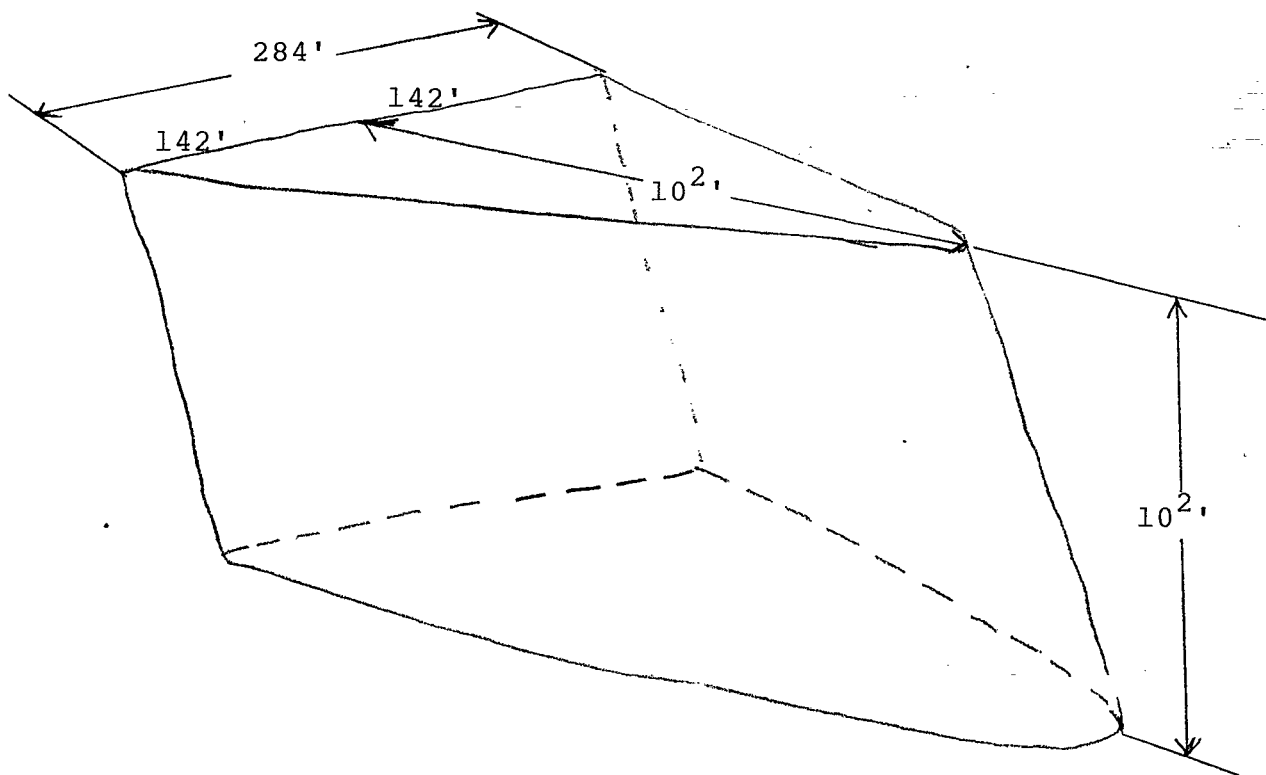
DATE : 6/18/90

SUBJECT: Calculations: Waste Volumes, Nanabah Vandever site

CONTACT SUMMARY REPORT:

See Attached:

1. ASSUME $d = h = 10^2$ ft AND THAT THE WASTE PILE GEOMETRY IS APPROXIMATED BY:



$$A = 1/2 bh$$

$$A = 1/2 (142')(10^2')$$

$$A = 7.1 \times 10^3 \text{ ft}^2$$

NAVAJO SUPERFUND OFFICE

Nanabah Vandever
Uranium Mine

JUNE '90 T. MORRIS

$$2. \quad V_{\text{GEO}} = [7.1(10^3) \text{ ft}^2][10^2 \text{ ft}] (2) \\ = 1.42 (10^6) \text{ ft}^3$$

3. Compensate that above volume for void volume overestimate

$$V_{\text{tp}} = .7 V_{\text{GEO}} = 9.94(10^5) \text{ ft}^3$$

4. Assume that the fraction of U_3O_8 present in the tailings is of the order of magnitude 10^{-4}

$$10^{-4} V_{\text{TP}} = V_{\text{U}_3\text{O}_8} = 9.94(10) \text{ ft}^3 \\ = 2.81(10^6) \text{ cm}^3$$

5. From General Assumptions the density of U_3O_8 was found to be 23.26 gm.cm^{-3} so that

$$\text{MU}_3\text{O}_8 = 6.55 (10^4) \text{ kg} \\ : 72.18 \text{ Tons}$$

$$06. \quad \frac{\text{WU}_3\text{O}_8}{\text{WV}_2\text{O}_5} = \frac{.22}{.18} = 1.22$$

$$. \text{WV}_2\text{O}_5 = 88.22 \text{ Tons}$$

$$7. \quad \text{WU}_3\text{O}_8 + \text{WV}_2\text{O}_5 = 160.4 \text{ Tons}$$

$$\text{QF} = 4$$

8. Assume the smaller, adjacent waste pile (B) to be 30% of the larger (Fig.5)

$$\text{Therefore: } \text{U}_3\text{O}_8 = 21.65 \text{ Ton}$$

$$\text{U}_2\text{O}_5 = 26.47 \text{ Tons}$$

9. Total Waste Quantities: $\text{U}_3\text{O}_8 = 93.83 \text{ Tons}$

$$\text{V}_2\text{O}_5 = 114.69 \text{ Tons}$$

GENERAL ASSUMPTIONS

1. Take $\rho_{ss} = 1.7 \text{ gm.cm}^{-3}$

Consider the U^{235} and U^{238} abundances (U^{234} negligible) whereby,

$$\text{"Fraction } U^{235}\text{"} = 7.2 (10^{-3})$$

$$\text{"Fraction } U^{235}\text{"} = .9927$$

Then derive the molecular weight of U_3O_8 as;

$$\begin{aligned} MW_{U_3O_8} &= [7.2 (10^{-3})] [(3) (235)] \\ &+ (.9927) (3) (238)] \\ &+ 8 (16) \\ &= 821.86 \end{aligned}$$

Likewise, derive the molecular weight of SiO_2 (sandstone).

$$\begin{aligned} MWSiO_2 &= 28.09 + 2 (16) \\ &= 60.89 \end{aligned}$$

$$\frac{MW_{U_3O_8}}{MWSiO_2} = \frac{821.86}{60.89} = 13.68$$

Then,

$$\frac{\rho_{U_3O_8}}{\rho_{ss}} = \frac{\rho_{U_3O_8}}{1.7} = 13.68$$

So that,

$$\rho_{U_3O_8} = 23.26 \text{ gm.cm}^{-3}$$

2. (From reference #22)

$$MW_{U^{235}} = 235 \text{ gm. mole}^{-1}$$

$$MW_{U^{238}} = 238 \text{ gm. mole}^{-1}$$

Yet, the atomic volume associated with ${}_{92}U^{235}$; periodic properties of elements

$$A_v = 12 \text{ cm}^3 \text{ mole}^{-1}$$

whereby,

$$A_v^{-1} MW_{U^{235}} = 19.58 \text{ gm.cm}^{-3}$$

and,

$$\begin{aligned} A_v^{-1} MW_{U^{238}} &= \rho_{U^{238}} \\ &= 19.83 \text{ gm.cm}^{-3} \end{aligned}$$

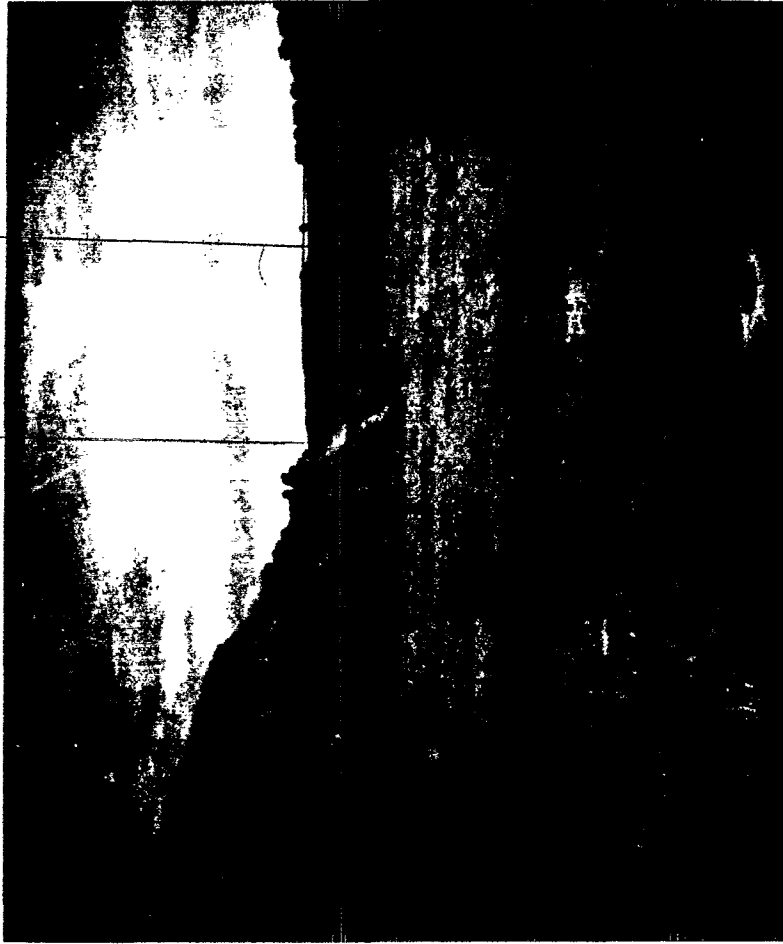
10-24-91



~~FRONT~~ V.
STATE LANDS

3rd FRAME

W: 54"
H: 50"



H: 50"
W: 54"

NANP - 141 VANDERBER

$$\frac{141 \left(\frac{19}{50} \right)}{10^2} = \frac{141 \left(\frac{54}{50} \right)}{19} = \frac{10^2 (54) (12)}{19} = 284 \text{ ft.}$$

REFERENCE #9

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

CONTACT REPORT

Meeting: ()

Telephone: (X)

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Christopher Mike, ASO 1, Navajo Water Development

PHONE: 602-871-6954

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 5/30/90

SUBJECT: Water well analysis for Haystack Mountain municipal well

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

See Attached:

WATER CHEMICAL ANALYSIS

NAVAJO TRIBAL UTILITY AUTHORITY



SAMPLE NO. 7115
 SAMPLE LOCATION Baca Haystack DATE COLLECTED 7-10-89
 DATE RECEIVED 7-10-89 COLLECTED BY C. G. Mike
 DATE OF FINAL ANALYSIS 8-10-89 ADDRESS Navajo Tribe
 TECHNICIAN Heaton

TEST	PARAMETER	METHOD	RESULTS	mg/l
✓	ALKALINITY	TITRAMETRIC	54.1946 (103)	
✓	CALCIUM	TITRAMETRIC OR AA	4.00436 (100)	75-200
✓	CHLORIDE	TITRAMETRIC	1.2 1946 (1)	250
✓	TOTAL HARDNESS	TITRAMETRIC	2.0 1946 (1)	500
✓	MAGNESIUM	CALCULATED OR AA	2.0 1946 (1)	
	MANGANESE	SPECTROPHOTOMETRIC OR AA		0.05
	IRON	SPECTROPHOTOMETRIC OR AA		0.3
✓	pH	ELECTRODE		6.5-8.5
✓	PHOSPHATE	SPECTROPHOTOMETRIC	1.0 1946 (1)	
✓	POTASSIUM	FLAME PHOTOMETER	1.17 1946 (1)	1000-2000
✓	SODIUM	FLAME PHOTOMETER	1.16 1946 (1)	
✓	SULFATE	TITRAMETRIC	1.2 1946 (1)	250
✓	TOTAL DISSOLVED SOLIDS	ELECTRODE	5.0 1946 (1)	500
✓	TURBIDITY	NEPHELOMETER	1.0 1946 (1)	
✓	FLUORIDE	ELECTRODE	1.0 1946 (1)	1.4

REMARKS: PH 11.0
 FORM NO. 5459

CHEMICAL ANALYSIS

NAVAJO TRIBAL UTILITY AUTHORITY
LABORATORY

16T-551

SAMPLE NUMBER 7115 PWSID NUMBER NM 0254 *
 SAMPLE LOCATION Baca Haystack DATE COLLECTED 7-10-89
 DATE RECEIVED 7-10-89 COLLECTED BY C. G. Mike
 DATE OUT 2-7-90 ADDRESS OLM
 TECHNICIAN Heaton

TEST	PARAMETER	METHOD	RESULTS	MCL
✗	ARSENIC	ATOMIC ABSORPTION	<.001	0.05
✗	BARIUM	ATOMIC ABSORPTION	.038	1.0
✗	CADMIUM	ATOMIC ABSORPTION	<.001	0.01
✗	CHROMIUM	ATOMIC ABSORPTION	.002	0.05
✗	IRON	ATOMIC ABSORPTION	.057	N/A
✗	LEAD	ATOMIC ABSORPTION	<.001	0.05
✗	MANGANESE	ATOMIC ABSORPTION	.005	N/A
✗	MERCURY	FLAMELESS ATOMIC ABSORPTION	.001	0.002
✗	SELENIUM	ATOMIC ABSORPTION	<.001	0.01
✗	SILVER	ATOMIC ABSORPTION	<.001	0.05
	NITRATE (AsN)	CADMIUM REDUCTION		10.0
	FLUORIDE	ELECTRODE		1.4

ELL No. 16T-551

DATE REPAIRED	WORK DONE AND MATERIALS USED
10/22/69	Used sucker rods, 2 $\frac{1}{2}$ " pipes for corner post, 2" pipe for grit and cross braces out of sucker rods.
11/20/69	Installed 14' aermotor, 2" x 21' pipe, 2-2" close nipples, 2" tee, 2" elbow and 2" short nipple.
1/13/70	Repainted windmill tower.
2/5/70	Installed 4,000 gal storage tank, 1 $\frac{1}{4}$ " x 2' pipe, 1 $\frac{1}{4}$ " stop & waste valve, 5-1 $\frac{1}{4}$ " elbow.
3/17/70	Welded leak on storage tank.
7/17/73	Repaired the 100 DC pump jack motor. Replace 1 $\frac{1}{2}$ " stop and waste valve.
09-27-74	<i>changed oil</i>
3/19/75 <i>Kurt</i>	Replaced stop and waste.
10-22-75	<i>Welded leaky 4,000 gal. tank (daystank)</i>

16T-551

This well was turned over to the Public Health Service to be use it for 86-121 project, 27,900 gallon storage tank is still existing on this well

7-30-81	METER READING
8-11-81	METER READING
8-14-81	" "
10-2-81	Routine Inspection
10-9-81	" "
10-13-81	THE TANK 11 $\frac{1}{2}$ & METER READING
10-19-81	ROUTINE INSPECTION
10-26-81	INSPECTION
9-4-81	Meter Reading
9-8-81	Tank 10'
9-14-81	Routine Check
9-18-81	Meter Reading
10-2-81	Routine Inspection.
10-9-81	Routine Inspection.
10-13-81	Tank 11 $\frac{1}{2}$ / Meter Reading
10-19-81	Routine Inspection.
10-26-81	Inspection
07-30-81	Meter Reading
08-11-81	Meter Reading
08-14-81	Meter Reading

RECORD

FILE

ENTERED OCT 8 1986

WELL NO 167-5511111 USGS AQUIFER CODE 23115N57C
C H N C

THICKNESS 11 FT NOMINAL YIELD 11 GPM YIELD MEASURED 1/1

(X) BAILER (✓) PUMP TEST @ 1150 GPM FOR 116 HOURS DATE 10/7/1976

DRAWDOWN 1167 FT OBSERVATION WELL DATA AVAILABLE () YES () NO

HORIZ CONDUCTIVITY 11.1 FT/DAY SPECIFIC CAPACITY 0.75 GPM/FT *after 4 hrs. Pumping.*

VERT. CONDUCTIVITY 11.1 FT/DAY STORAGE COEF .111111

COEF OF TRANSMISSIVITY .85 FT²/DAY *OR 660 GPD/FT.*

INDICATE ADDITIONAL PUMPING TEST DATA AVAILABLE AS HARD COPY:

- () Y () N MULTIPLE RATE DRAWDOWN PUMPING TEST
- (✓) Y () N SINGLE RATE DRAWDOWN PUMPING TEST
- () Y () N MULTIPLE RATE DRAWDOWN/RECOVERY TEST
- (✓) Y () N RECOVERY TEST

LOGS AVAILABLE: (✓) DL DRILLER'S LOG () EL ELECTRIC LOG

HYDROLOGY DATA SOURCE: TRIBE 11111111111111111111

HYDROLOGY FILE COMPLETED BY: M. Z. DATE 10/8/1986

STATIC WATER LEVEL FILE

see
 ENTERED OCT 8 1986 DEPTH TO SWL 446 FT DATE 9/17/1969 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL 417 FT DATE 10/7/1976 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1
 DEPTH TO SWL _____ FT DATE 1/1 DEPTH TO SWL _____ FT DATE 1/1

IBAL WELL RECORD STRUCTURE FILE

ENTERED

WELL NO 167-551 STARTED 9/11/1969 COMPLETED 9/17/1969

ELEVATION 10890 FT DEPTH 11083 FT DEPTH MEASURED 9/17/1969

DEPTH IS ☒ MEASURED () ESTIMATED () REPORTED WELL DIA. 9.00 IN

1 CASING DIA 7.00 FROM 11083 FT TO 11083 FT MATL STC

2 CASING DIA 7.00 FROM 11083 FT TO 11083 FT MATL STC

3 CASING DIA 7.00 FROM 11083 FT TO 11083 FT MATL STC

4 CASING DIA 7.00 FROM 11083 FT TO 11083 FT MATL STC

casing matl codes brs=brass cop=copper evd=everdur irn=iron mon=monel
pls=plastic stl=steel sst=stainless steel

1 CASING PERFORATED FROM 11083 FT TO 11053 FT OPENING TYPE P

2 CASING PERFORATED FROM 11083 FT TO 11083 FT OPENING TYPE

3 CASING PERFORATED FROM 11083 FT TO 11083 FT OPENING TYPE

4 CASING PERFORATED FROM 11083 FT TO 11083 FT OPENING TYPE

5 CASING PERFORATED FROM 11083 FT TO 11083 FT OPENING TYPE

opening codes: f=fractured rock, l=louvered or shutter-type screen,
m=mesh screen, p=perforated, porous, slotted casing, r=wire-wound screen
s=screen, type unknown, t=sand point, w=walled or shored, x=open hole
z=other

DATE WELL TURNED OVER TO TRIBE: / /

FUNDED BY: CONTRACTOR:

SITE IMPROVEMENTS

- () WM WINDMILL
- () WP WATERING POINT
- ☒ TA TANK
- () WL WATER LINE
- () TR TROUGH
- () CS CISTERN
- () HP HAND PUMP
- () NO NONE

TYPE OF LIFT

- () AL AIRLIFT
- () PS PISTON
- () TU TURBINE
- () MT MULTIPLE TURBINE
- () CN CENTRIFUGAL
- () MC MULTIPLE CENTRIFUGAL
- () BU BUCKET

ENERGY SOURCE

- ☒ EM ELECTRIC MOTOR
- () DE DIESEL ENGINE
- () HA HAND
- () GS GAS ENGINE
- () LP LP GAS ENGINE
- () NG NATURAL GAS ENGINE
- () WM WINDMILL
- () SO SOLAR

☒ ☒ () SU SUBMERSIBLE

PUMP HP ON SITE STORAGE CAPACITY GAL

STRUCTURE DATA SOURCE: TR/BL

STRUCTURE FILE COMPLETED BY: M. Z. DATE 10/8/1986
rev:840426 form: well record str

TRIBA
COM

RD

TRIBAL WELL NO V16T-5511111

PERTINENT

COMMENTS: The Haystack Community System serves approximately
140 homes in the area (Dale Cartmel INS Engineer's Letter to
Anson Damon Jr. February 5, 1979).

⊗ A bailer test was also run @ 20 GPM for 6 hours,
the drawdown was 41 feet on September 17, 1969.

* T Calculated from INS Pump Test data Time/Drawdown
Curve on file.

⊗⊗ Originally the well was used as a stock well and
used to have a windmill, storage tank, troughs etc.
Now well is being used for Haystack Community
Water Supply System Since December 20, 1976 and
has an electric pump, water tank and a complete
control house and the water distribution system.

— Water quality information on file. Water quality
is acceptable for Public water supply.

— property easement is on file

ENTERED OCT 09 1986

RECORD

Water Well Development
Navajo Tribe
Window Rock, Arizona

WELL NO. 16T-

Quad. No. 119 Miles west 10.65 Miles south 11.00

1 mile SE of Haystack Mountain

Location

Began well September 11, 1969 Finished well September 17, 1969

Diameter of well 9.00" Depth of well 1083'

Static water level 446' Drawdown 41' Recovery

Quantity of water on test run: bailer: pump: 21 G. P. M. Tested for 6 hours

Kind of casing: T & C Sizes and length 7" OD x 1085'

PERFORATION: See Attached Sheet

Screen kind Length Mesh

Contractor THE NAVAJO TRIBE Address Window Rock, Az
DRILLERS: B. Yazzie & j. Sam FAILING - 2500 Rotary

DEPTH

LOG

From	To	Formation	Acquifer	Remarks
0	55	Top soil brown	sand - soft	
55	79	Black Volcanic	materials - hard	
79	180	Red shale -	soft	
180	190	Red shale and	white clay - soft	
190	255	Red shale and	purple shale	
255	350	Red shale -	soft	
350	376	Red shale and	purple sandstone - soft	
376	465	Red shale -	soft	
465	470	Red shale and	purple and white sandstone - soft	
470	803	Red shale -	soft	
803	807	Purple and white	sandstone - soft	
807	819	Red and purple	shale	
819	822	Purple	sandstone	
822	911	Medium grain with	to red sandstone - soft	
911	916	White clay -	soft	
916	935	Brown to white	sandstone - soft	
935	1083	Red brownish	sandstone - soft and hard	

Remarks:

S.P.

Tota Salts	Calcium Ca.	Magnesium Mg.	Sodium Na.	Chlorides Cl	Sulfates SO 4	Carbonates HCO 3	P.H.	CO 3

Excellent Good Fair Poor Doubtful Not suitable for domestic, livestock use

TRIBAL WELL RECORD
LOCATION FILE

CT 6 1986 *fur*

TRIBAL WELL NO [1]6[7]-[5]8[6] [] [] []

PWSID [W]M[0]0[0]0[2]5[4]

WELL NAME/OTHER NO [M]A[Y]S[T]A[C]K [R]U[R]A[L] [W]A[T]E[R] [S]U[P]L[Y]
WELL.

WELL TYPE
(MARK ONE ONLY)

WELL STATUS
(MARK ONE ONLY)

WELL USE
(MARK ONE ONLY)

☒ WW WATER WELL
☐ WA ARTESIAN WELL
☐ WS SPRING
☐ OW OBSERVATION WELL
☐ GS GAS WELL
☐ OP OIL PRODUCTION
☐ MW MINERAL WELL

☐ ACT ACTIVE
☐ INA INACTIVE
☒ ABA ABANDONED

☒ DOM DOMESTIC
☒ AGR AGRICULT.
LIVESTOCK
☐ IND INDUSTRIAL
MINING
☐ REC RECREATION
☐ MUN MUNICIPAL
☐ OTH OTHER

QUAD NO [1]1[9]

MILES WEST [1]0[.]4[5]

MILES SOUTH [1]9[.]8[0]

(NE) SE SW NW/NE SE SW (NW) (NE) SE SW NW [1]8 [T]1[3].0[W] [R]10.0[W]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

APPROXIMATE LOCATION [N]E[A]R [M]A[Y]S[T]A[C]K [M]O[U]N[T]A[I]N [] [] []

[] [] [] [] [] [] [] [] LATITUDE [3]5[2]1[4]3 LONGITUDE [1]0[7]5[6]0[2]

UTM COORDINATES: X(east) [] [] [] [] [] [] Y(north) [] [] [] [] [] [] ZONE [] []

OPERATOR [T]R[1]8[E] [0]4[M] USGS WATERSHED CODE [] [] [] [] [] [] [] [] [] []

STATE: ☐ AZ ARIZONA ☒ NM NEW MEXICO ☐ UT UTAH ☐ CO COLORADO

COUNTY: ☐ AP APACHE ☒ MK MCKINLEY ☐ SJ SAN JUAN ☐ MT MONTEZUMA
☐ NA NAVAJO ☐ VL VALENCIA ☐ KA KANE ☐ LP LA PLATA
☐ CO COCNINO ☐ BL BERNALLILLO
☐ SD SANDOVAL
☐ SO SOCORRO
☐ RA RIO ARriba
☐ SA SAN JUAN

GRAZING DISTRICT [1]6

CHAPTER NAME BACA CHAPTER CODE [8]A[C]A

LOCATION DATA SOURCE: [T]R[1]8[E] [1]4[S] [8] [5]T[0]N[E] [R]T-[6] [] []

LOCATION FILE COMPLETED BY: Masud U. Zaman DATE 10/3/1986

FIELD CHECKED BY: [] [] [] [] [] [] [] [] [] [] [] [] [] [] [] [] DATE 1/1/

C R D
E

July

PWSID [] [] [] [] [] [] [] []

W E L L U S E
(MARK ONE ONLY)

() DOM DOMESTIC
() AGR AGRICULT.
(☒) LIV LIVESTOCK
() IND INDUSTRIAL
MINING
() REC RECREATION
() MUN MUNICIPAL
() OTH OTHER

form:well record loc

ENTERED NOV 26 1986

T R I B A L
L O C A T D

TRIBAL WELL NO [167-522 1 1 1 1] PWSID [1 1 1 1 1 1 1 1]

WELL NAME/OTHER NO [1 1]

W E L L T Y P E
(MARK ONE ONLY)

W E L L S T A T U S
(MARK ONE ONLY)

W E L L U S E
(MARK ONE ONLY)

☒ WW WATER WELL
() WA ARTESIAN WELL
() WS SPRING
() OW OBSERVATION WELL
() GS GAS WELL
() OP OIL PRODUCTION
() MW MINERAL WELL

() ACT ACTIVE
() INA INACTIVE
☒ ABA ABANDONED
() UNK UNKNOWN

() DOM DOMESTIC
() AGR AGRICULT.
☒ LIV LIVESTOCK
() IND INDUSTRIAL
MINING
() REC RECREATION
() MUN MUNICIPAL
() OTH OTHER
() UNK

QUAD NO [1 1 1] MILES WEST [1 1 . 1 1] MILES SOUTH [1 1 . 1 1]

NE SE SW NW/NE SE SW NW/NE SE SW NW [22] [T]/[13].[00] [R]/[10].[00]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

APPROXIMATE LOCATION [1 1]

[1 . 1 1 1 1 1 1 1 1] LATITUDE [1 1 1 1 1 1] LONGITUDE [1 1 1 1 1 1]

UTM COORDINATES: X(east) [7821774] Y(north) [39151615] ZONE [12]

OPERATOR [TAL/BE 105M] USGS WATERSHED CODE [1 1 1 1 1 1 1 1 1 1]

STATE: () AZ ARIZONA ☒ NM NEW MEXICO () UT UTAH () CO COLORADO

COUNTY: () AP APACHE ☒ MK MCKINLEY () SJ SAN JUAN () MT MONTEZUMA
() NA NAVAJO () VL VALENCIA () KA KANE () LP LA PLATA
() CO COCNINO () BL BERNALLILLO
() SD SANDOVAL
() SO SOCORRO GRAZING DISTRICT [16]
() RA RIO ARRIBA
() SA SAN JUAN

CHAPTER NAME _____ CHAPTER CODE [BACD]

LOCATION DATA SOURCE: ☒ [1 1]

LOCATION FILE COMPLETED BY: _____ DATE / /

FIELD CHECKED BY: [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1] DATE / /

rev:840425 form:well record loc

**TRIBAL WELL
LOCATION**

ENTERED OCT 8 1986 *SK*

TRIBAL WELL NO [1][6][8]-[3][8]

PWSID [] [] [] [] [] [] [] []

WELL NAME/OTHER NO [C][C][C]-[E]-[9]

WELL TYPE
(MARK ONE ONLY)

WELL STATUS
(MARK ONE ONLY)

WELL USE
(MARK ONE ONLY)

☒ WW WATER WELL
☐ WA ARTESIAN WELL
☐ WS SPRING
☐ OW OBSERVATION WELL
☐ GS GAS WELL
☐ OP OIL PRODUCTION
☐ MW MINERAL WELL

☒ ACT ACTIVE?
☐ INA INACTIVE
☐ ABA ABANDONED

☐ DOM DOMESTIC
☒ AGR AGRICULT.
 LIVESTOCK
☐ IND INDUSTRIAL
 MINING
☐ REC RECREATION
☐ MUN MUNICIPAL
☐ OTH OTHER

QUAD NO [1][1][9]

MILES WEST [9].[6][0]

MILES SOUTH [8].[4][5]

NE SE SW (NW) NE SE SW (NW) NE SE SW NW [0][8] [1][1][3].[0][M] [R][1][0].[0][M]
 10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

APPROXIMATE LOCATION [8] [M] [L] [E] [E] [A] [S] [T] [0] [F] [8] [A] [C] [A] [] [] [] [] [] []

[] [] [] [] [] [] [] [] LATITUDE [3][5][2][2][3][8] LONGITUDE [1][0][7][5][5][0][8]

UTM COORDINATES: X(east) [] [] [] [] [] [] Y(north) [] [] [] [] [] [] ZONE [] []

OPERATOR [T][R][1][8][E] USGS WATERSHED CODE [] [] [] [] [] [] [] []

STATE: ☐ AZ ARIZONA ☒ NM NEW MEXICO ☐ UT UTAH ☐ CO COLORADO

COUNTY: ☐ AP APACHE ☒ MK MCKINLEY ☐ SJ SAN JUAN ☐ MT MONTEZUMA
 ☐ NA NAVAJO ☐ VL VALENCIA ☐ KA KANE ☐ LP LA PLATA
 ☐ CO COCNINO ☐ BL BERNALLILLO
 ☐ SD SANDOVAL
 ☐ SO SOCORRO GRAZING DISTRICT [1][6]
 ☐ RA RIO ARRIBA
 ☐ SA SAN JUAN

CHAPTER NAME BACA CHAPTER CODE [8][A][C][A]

LOCATION DATA SOURCE: [T][R][1][8][E] [8].[5][T][0][M][E] [R][1]-[6] [] [] [] [] []

LOCATION FILE COMPLETED BY: Masael A. Zaman DATE 10/7/1986

FIELD CHECKED BY: [] [] [] [] [] [] [] [] [] [] [] [] [] [] DATE 1/1

L NO. 16T-521

DEPTH

Remarks:

S.P. 750 Temp: 78°

NTRD. 61

L W E L L R E C O R D U C T U R E F I L E

ENTERED 00

WELL NO 1010121111 STARTED 10/15/1963 COMPLETED 11/10/1963

ELEVATION 17050 FT DEPTH 414 FT DEPTH MEASURED 11/13/1963

DEPTH IS (☒) MEASURED () ESTIMATED () REPORTED WELL DIA. 8.00 IN

1 CASING DIA 6.62 FROM 100 FT TO 414 FT MATL STL

2 CASING DIA 1.11 FROM 111 FT TO 111 FT MATL 111

3 CASING DIA 1.11 FROM 111 FT TO 111 FT MATL 111

4 CASING DIA 1.11 FROM 111 FT TO 111 FT MATL 111

casing matl codes brs=brass cop=copper evd=everdur frn=iron mon=monel
pls=plastic stl=steel sst=stainless steel

1 CASING PERFORATED FROM 1320 FT TO 414 FT OPENING TYPE P

2 CASING PERFORATED FROM 111 FT TO 111 FT OPENING TYPE 11

3 CASING PERFORATED FROM 111 FT TO 111 FT OPENING TYPE 11

4 CASING PERFORATED FROM 111 FT TO 111 FT OPENING TYPE 11

5 CASING PERFORATED FROM 111 FT TO 111 FT OPENING TYPE 11

opening codes: f=fractured rock, l=louvered or shutter-type screen,
m=mesh screen, p=perforated, porous, slotted casing, r=wire-wound screen
s=screen, type unknown, t=sand point, w=walled or shored, x=open hole
z=other

DATE WELL TURNED OVER TO TRIBE: 1/1/

FUNDED BY: 7101012111 CONTRACTOR: 7101012111

SITE IMPROVEMENTS

(☒) WM WINDMILL
(☒) WP WATERING POINT
(☒) TA TANK
() WL WATER LINE
() TR TROUGH
() CS CISTERN
() HP HAND PUMP
() NO NONE

TYPE OF LIFT

() AL AIRLIFT
(☒) PS PISTON
() TU TURBINE
() MT MULTIPLE
TURBINE
() CN CENTRIFUGAL
() MC MULTIPLE
CENTRIFUGAL
() BU BUCKET
() SU SUBMERSIBLE

ENERGY SOURCE

() EM ELECTRIC MOTOR
() DE DIESEL ENGINE
() HA HAND
() GS GAS ENGINE
() LP LP GAS ENGINE
() NG NATURAL GAS ENGINE
(☒) WM WINDMILL
() SO SOLAR

PUMP HP 1111 ON SITE STORAGE CAPACITY 127900 GAL

STRUCTURE DATA SOURCE: 7101012111

STRUCTURE FILE COMPLETED BY: _____

rev:840426

M.2. DATE 10/9/1964
form: well record str

TRIBAL WELL RECORD
COMMENTS FILE

TRIBAL WELL NO [1][6][7]-[5][2][1][][][][]

PERTINENT

COMMENTS: water quality information on file.

- additional 1000 gallons elevated tank for winter hauling.

ENTERED OCT 13 1986 JUN

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

WELL SCHEDULE

Date 23 December 1963 Well No. W-100

Record by McIntire G.W. No.

Source of data Tanner well record - above bar

1. Location: State Nevada County McIntire
Map & name of land

2. Owner: Tanner Address Widow's Hill

Tenant Address
Driller Bill Self - Tanner Address

3. Topography Crete slope

4. Elevation 7250 ft. above

5. Type: Drilled (bore, bored, jetted, etc.) 10.45

6. Depth: 114 ft. Meas.

7. Casing: ft. Meas.

Depth 114 ft. Finish ft.

8. Chief Aquifer Entrada From ft. to ft.

Others

9. Water level 36.5 ft. 11-13 1963 above 2.5 below surface

10. Pump: Type Capacity G. M.

Power: Kind Horsepower

11. Yield: Flow G. M. G. M.

Drawdown 49 ft. after 1 hours pumping G. M.

12. Use: Stock (PS, RT, Ind, Irr, Oth.)

Adequacy of performance

13. Quantity 1.5 750 Temp 78 °F

Taste, odor, color Sample 11-63

Unit for

14. Remarks: (Log, Analysis, etc.) Drilled log as well record

Contacts as best (over)

30-Aug-89 12:12 PM

UNITED STATES TESTING COMPANY INC.
2800 GEORGE WASHINGTON WAY, RICHLAND, WA
RADIOCHEMICAL ANALYSIS REPORT
Results reported on 890830

page 1

SAMPLE TYPE	CUST#	ISOTOPE	RESULT	COUNTING ERROR	OVERALL ERROR	ANALYSIS SIZE	PERCENT MOIST	SAMPLE DATE TIME	ON DATE TIME	U C	GROUP	UB#
** Reported => 890830												
WATER DATE	NM0254 DATE	ALPHA DATE	112 * 1.13E+00 PCI/L	2.86E+00	2.90E+00(28)	5.60E-02 L		890710 1315	890710 1315	I 103	079180	

14 Records listed

NM0254 BACA/HAYSTACK COMMUNITY

SEP 3

DOMESTIC SECTION

* Denotes a result less than the overall error(NS) specifies the level of error, 1 sigma or 2 sigma

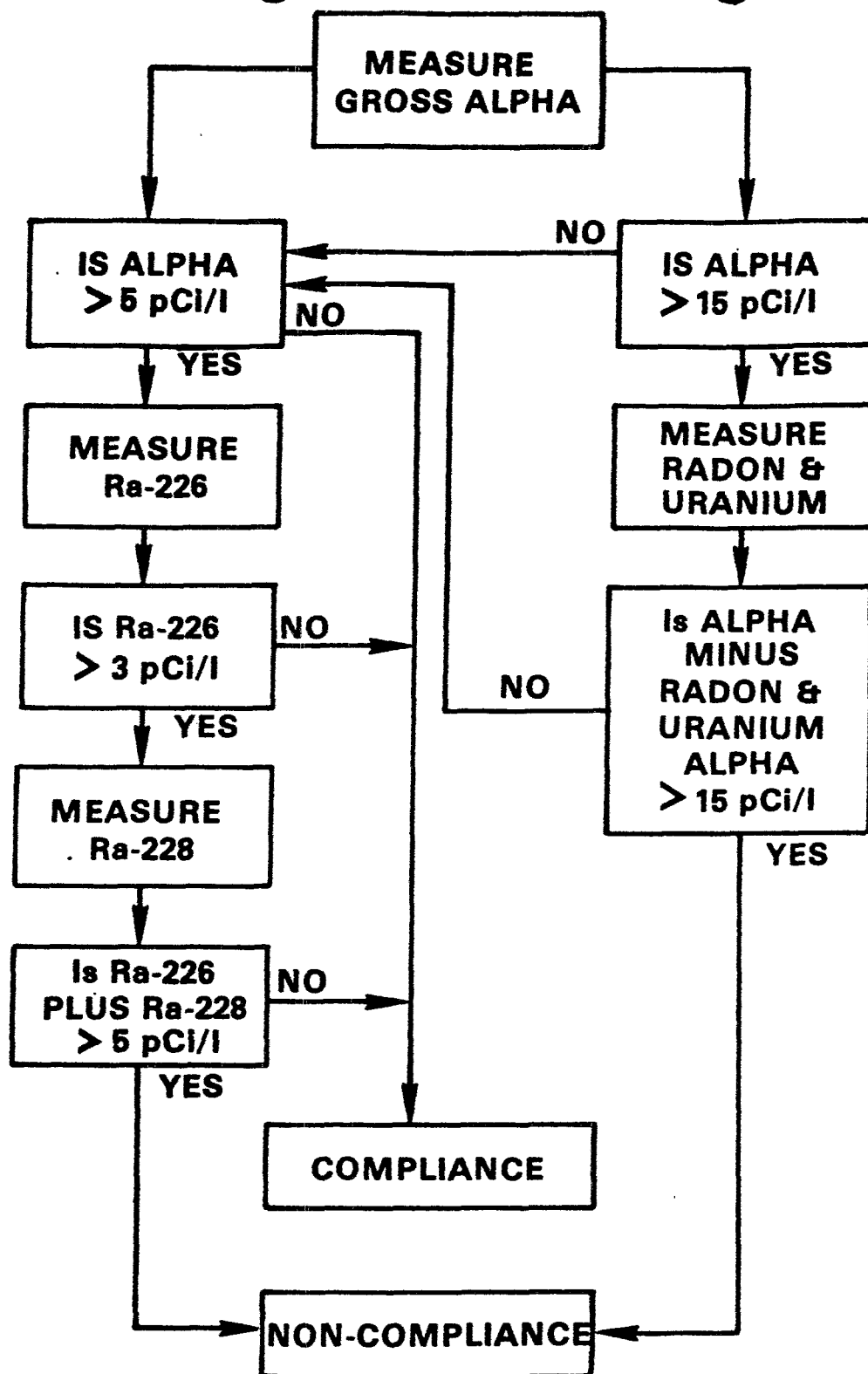


Figure 9 Flow chart for gross alpha particle activity monitoring (U.S. EPA, Las Vegas, Environmental Monitoring and Support Laboratory). Note that it is not a requirement that radon and uranium be measured if the gross alpha activity is greater than 15 pCi/l.

REFERENCE #11

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90



POTENTIAL HAZARDOUS WASTE SITE IDENTIFICATION

REGION

SITE NUMBER

NOTE: The initial identification of a potential site or incident should not be interpreted as a finding of illegal activity or confirmation that an actual health or environmental threat exists. All identified sites will be assessed under the EPA's Hazardous Waste Site Enforcement and Response System to determine if a hazardous waste problem actually exists.

A. SITE NAME Nanabah Vandever Uranium Mine		B. STREET (or other identifier) Haystack Mtn., NM T13N R11W	
C. CITY Prewitt	D. STATE NM	E. ZIP CODE 87045	F. COUNTY NAME McKinley
G. OWNER/OPERATOR (if known) 1. NAME Nanabah Vandever Heirs (31 total)		2. TELEPHONE NUMBER BIA 505-786-6116	
H. TYPE OF OWNERSHIP (if known) <input checked="" type="checkbox"/> 1. FEDERAL <input type="checkbox"/> 2. STATE <input type="checkbox"/> 3. COUNTY <input type="checkbox"/> 4. MUNICIPAL <input checked="" type="checkbox"/> 5. PRIVATE <input type="checkbox"/> 6. UNKNOWN			
I. SITE DESCRIPTION <p>The Nanabah Vandever abandoned mine site is an open pit(?) on the south side of Haystack Mountain. It occurs in an outcropping of Todilto limestone. Waste from the pit was dumped over the side of the outcrop onto the plain below. The waste piles are approximately 100 ft high. There is no evidence of physical restraints, barriers, or warnings.</p>			
J. HOW IDENTIFIED (i.e., citizen's complaints, OSHA citations, etc.) Navajo Superfund Office Field Survey			K. DATE IDENTIFIED (mo., day, & yr.) Fall '89
L. SUMMARY OF POTENTIAL OR KNOWN PROBLEM <p>Potential exposures of radioactive progenies Thorium, Radon, Radium, Bismuth, and Polonium and toxic heavy metals Uranium, Vanadium, Lead, Selenium, Arsenic, Barium, and Molybdenum to local residents via surface and ground water leachate and air migration exist. The combined effects of this site and adjacent sites are cause for concern and attention. Scintillometer readings near the site were 100mR/hr, compared with a background of 6mR/hr, and 2.5×10^4 CPM of Bi which correlates to approximately 2.5×10^3 Rn/cm³.</p> <p>Livestock were observed grazing at the base of the waste piles leading to possible bioaccumulation of toxic elements in the animals and the people who eat them.</p>			
M. PREPARER INFORMATION 1. NAME Tom Morris		2. TELEPHONE NUMBER 602-871-7330	3. DATE (mo., day, & yr.) 6/28/90

REFERENCE #10

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT

Meeting: ()

Telephone: (X)

Other: ()

CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Yolanda Barney, Data Manager, Navajo Natural Heritage Program

PHONE: 602-871-6472

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 6/5/90

SUBJECT: Threatened/Endangered Species, Haystack Mountain, NM

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

SEE ATTACHED:



received
6/5/90

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

THE NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION

June 5, 1990

MEMORANDUM

TO : Data Manager
Navajo Fish and Wildlife

THROUGH: CBN
Clara Bia, Director
Navajo Superfund Office

FROM : Tom Morris
Tom Morris, Environmental Specialist
Navajo Superfund Office

SUBJECT: Threatened and endangered species in the Haystack
Mountain, New Mexico area

The Navajo Superfund Office is conducting preliminary assessments on three abandoned uranium sites near Haystack Mountain, NM. Part of the assessment investigation deals with threatened or endangered fauna or flora species within fifteen miles of the site. I would appreciate any data you have pertaining to threatened or endangered species in the Haystack area. Haystack Mountain is in sections 13 and 18 on the Bluewater Quad, New Mexico. Thank you for your time and efforts.

*orig. on Arizona
BPR. examine closely to see*

Mexican free-tailed bat, Tadarida Brasilensis are nearby, potential.

Are any seeps or springs to be effected? watershed protection near

Mexican spotted owl (Strix occidentalis) potential

Goshawk potential

Sharpshinned hawk potential

6-7-90 PFR

THE NAVAJO NATION

Leonard Haskie
Interim President
Navajo Nation



Irving Billy
Interim Vice President
Navajo Nation

June 7, 1990

MEMORANDUM

TO : Tom Morris, Environmental Specialist
Navajo Superfund Office

FROM : Yolanda Barney
Yolanda Barney, Data Manager
Navajo Natural Heritage Program

SUBJECT: THREATENED AND ENDANGERED SPECIES: HAYSTACK, NM

A request of Threatened and Endangered species was made to our office on June 5, 1990. Our staff of biologists reviewed the project and below is a list of potential species of concern.

Black footed-ferrets (Mustela nigripes) and burrowing owls (Athene cunicularia) should be considered anytime a prairie dog town is encountered.

Rhizome fleabane (Erigeron rhizomatus) may be found near the project site.

This report contains potential occurrences of species of concern in the vicinity of a given project. It is based on existing information known to the Heritage Program at the current time. It should not be regarded as a final statement on occurrences of species of concern nor should it substitute for onsite surveys for these species.

REFERENCE #13

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

Uncontrolled Hazardous Waste Site Ranking System

A Users Manual (HW-10)

Originally Published in
the July 16, 1982, *Federal Register*

United States
Environmental Protection
Agency

1984

TABLE 2
PERMEABILITY OF GEOLOGIC MATERIALS*

Type of Material	Approximate Range of Hydraulic Conductivity	Assigned Value
Clay, compact till, shale; unfractured metamorphic and igneous rocks	$<10^{-7}$ cm/sec	0
Silt, loess, silty clays, silty loams, clay loams; less permeable limestone, dolomites, and sandstone; moderately permeable till	$10^{-5} - 10^{-7}$ cm/sec	1
Fine sand and silty sand; sandy loams; loamy sands; moderately permeable limestone, dolomites, and sandstone (no karst); moderately fractured igneous and metamorphic rocks, some coarse till	$10^{-3} - 10^{-5}$ cm/sec	2
Gravel, sand; highly fractured igneous and metamorphic rocks; permeable basalt and lavas; karst limestone and dolomite	$>10^{-3}$ cm/sec	3 ²

*Derived from:

Davis, S. N., Porosity and Permeability of Natural Materials in Flow-Through Porous Media, R.J.M. DeWiest ed., Academic Press, New York, 1969

Freeze, R.A. and J.A. Cherry, Groundwater, Prentice-Hall, Inc., New York, 1979

REFERENCE #14

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

NAVAJO NATION F A X 88



TECHNICAL SUPPORT DEPARTMENT
Commission for Accelerating Navajo Development Opportunities
P. O. Box 663
Window Rock, Navajo Nation (AZ) 86515

602/871-6754

September 1988

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SUMMARY OF 1980 CENSUS NAVAJO RESERVATION DATA ON SELECTED SUBJECTS

MEMBERSHIP

96.7% of Indian persons on the reservation were enrolled members of the Tribe.

LONG-TERM RESIDENCY

81.9% of Indian persons 1 year old and older on the reservation had always lived on the reservation, never off-reservation.

MEDIAN AGE

18.7 Years

INCOME (Per Capita)

<u>1970 Census</u>	<u>1980 Census</u>
\$776	\$2,414

INCOME (Median Family)

<u>1970 Census</u>	<u>1980 Census</u>
\$3,084	\$9,079

POVERTY STATUS (% Persons)

<u>1970 Census</u>	<u>1980 Census</u>
64.5	49.7

POVERTY STATUS (% Families)

<u>1970 Census</u>	<u>1980 Census</u>
62.1	47.3

25.8% of Indian households on reservation received food stamps in 1979.

38.0% of Indian persons 15 & older received financial assistance in 1979.

FAMILY CHARACTERISTICS

5.14 Persons per family

73.9% of Indian families on the reservation had 1 or more minor children,

40.5% had 1 or more children under 6 years of age.

24.3% of Indian families had female heads, with no husbands present.

EDUCATION

50.9% of those 5-19 years old were enrolled in school.

24.3% of those 16-19 years old were not enrolled and not HS graduates.

37.4% of those 25 years & older completed less than 5 years of school;

34.1% were high school graduates.

HEALTH CARE

83.6% of Indian persons received health care in previous year.

87.5% of these persons received health care at IHS facilities.

05.9% paid for their own care.

03.0% had private health insurance.

00.9% received medicaid or medicare benefits.

39.8% were able to get a health facility within 30 minutes.

28.4% required 30-60 minutes to reach a health care facility.

31.8% required more than 1 hour to reach a health care facility.

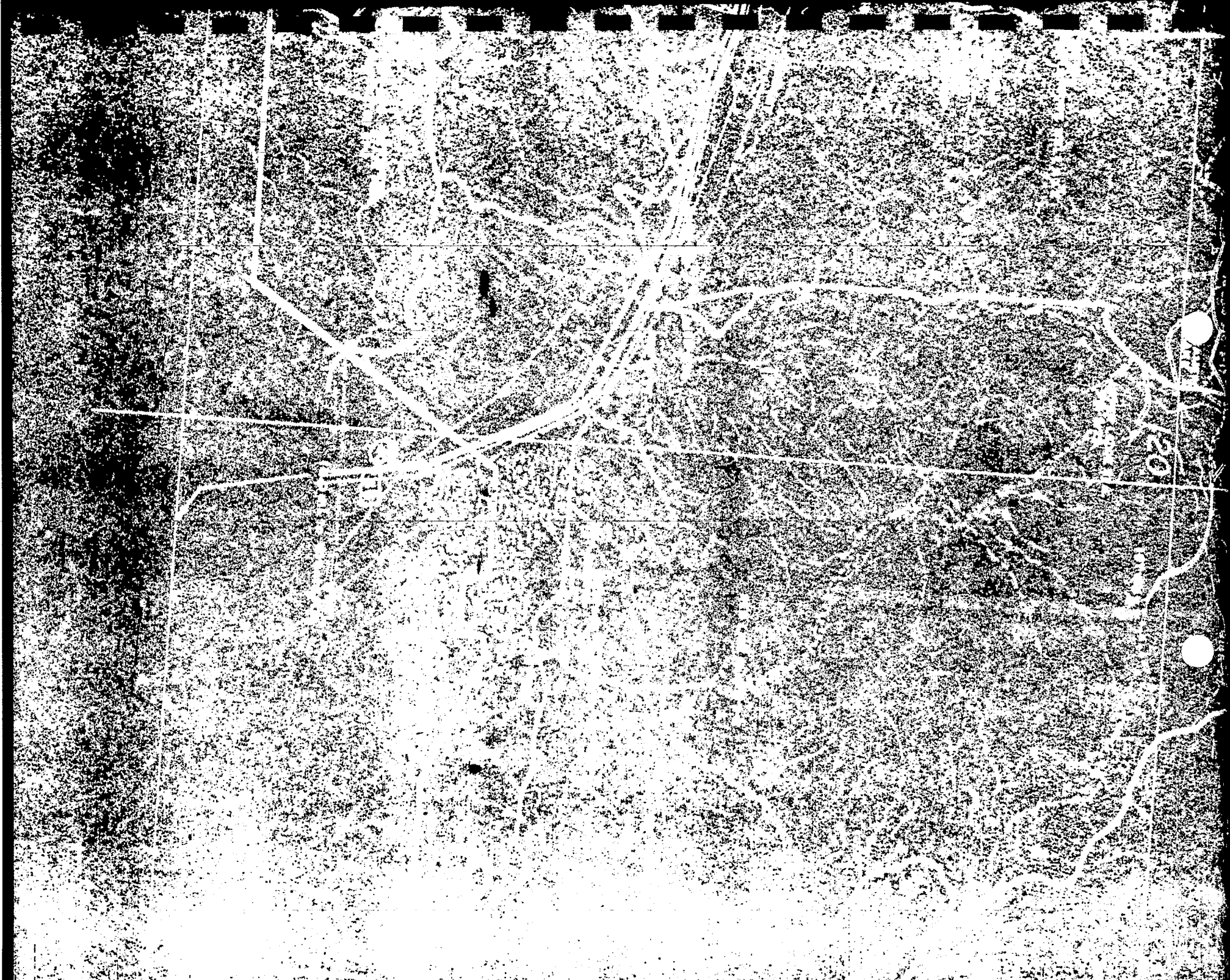
REFERENCE #15

NAVAJO SUPERFUND OFFICE

NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90



REFERENCE #16

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

coordinates for centroid easting = 777975 meters northing = 3915441 meters

[illegible]

```

window coordinates > minimum east minimum north maximum east maximum north
                        771475      3908941      784475      3921941

```

WELLNO	EAST	NORTH	DRILLED	DEPTH	SWL	AQUIFER	OPERATOR
00-3289	780150	3909728	7 / 7	351.0	64.0	231CHNL	BERRYHILL
00-3332	780150	3909728	1 / 1/57	725.0	243.7	313SADG	BERRYHILL
00-3341	773644	3910762	11 / 5/57	200.0	60.4	231CHNL	GIBBS
16B-38 ✓	779911	3919037	5/12/36	357.0	331.0	221SMVR	TRIBE O&M
16T-521	778415	3916770	11/13/63	414.0	365.0	221ENRD	TRIBE O&M
16T-522 ✓	782794	3915615	0 / 0 / 0	270.0	0.0		TRIBE O&M
16T-551 ✓	779489	3915538	9/17/69	1083.0	417.0	231SNSL	TRIBE O&M
16T-552 ✓	774942	3916262	10 / 9/69	1268.0	362.0	231CHNL	TRIBE O&M
16T-586 ✓	778600	3917300	6/18/76	2400.0	47.0		TRIBE O&M

WINDMILL MAINTENANCE

16T-521

DATE REPAIRED	WORK DONE AND MATERIALS USED
8/19/69	Run in sucker rods & made new stand pipe. Used 3/4" x 420' sucker rods, 1 1/4" gate valve, 1 1/4" x 4" short nipple, 2" x 15' pipe.
8.18.69	Pulled rods
9/12/69	Checked windmill and changed oil.
3/17/70	Checked windmill, ok.
3/19/70	Releathered cups.
09-27-74	CHANGED OIL
10-16-75	Remove Pump jack, but local 10-42's advised not till 351 tank is fixed.
10-22-75	Removed the pump jack to station 19

16T-521

Well equipped iwth 16' Aermotor windmill 27,900 gallon storage tank 1,000 gallon Army surplus storage tank elevated where people filled their barrel with drinking water. The big tank is empty.

USGS-WRD
Form GW

16T-521

ANALYTICAL STATEMENT
Ariz. 6.16

COUNTY McKinley
LAS NO 53507

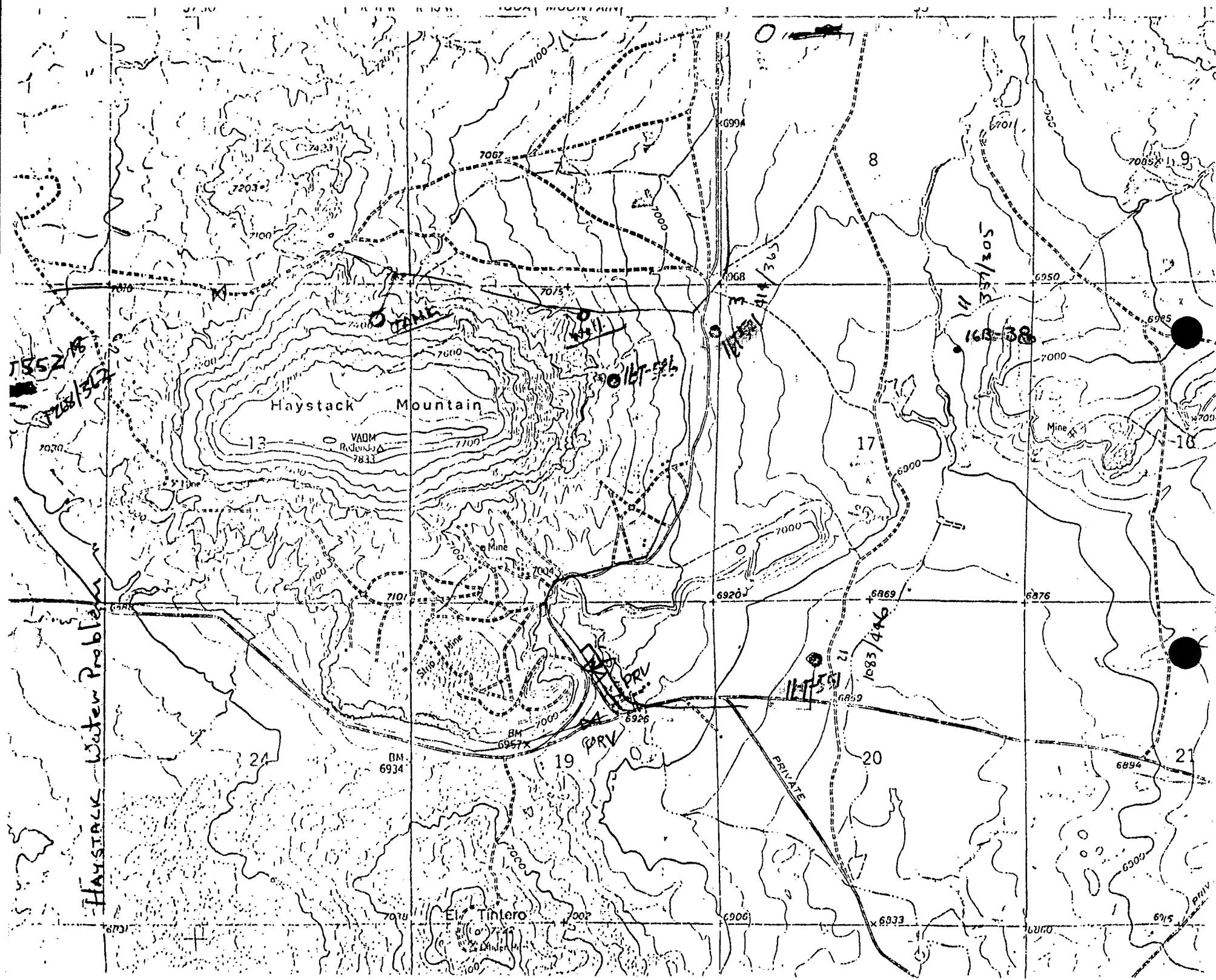
119

Location 10.5W x 10.0S
6 miles NE of Prewitt,
N.M. Drilled
Source (type of well)
Owner Navajo Tribe
Window Rock, Ariz.
Date drld Nov. '63 Cased to 414 ft
Depth 414' Diam 6 5/8"
WEP Entrada
Water level 365 ft below surf.
Sampled after pumping hrs
Yield 2 - 3 GPM (meas or est)
Pt of coll Well
Appearance Reddish
Temp (°F) Use Dom., Stock
Collector Fred Zsach
Chemist EFW
Date completed Feb. 14, 1964
Checked by JON
Date transmitted Mar. 3, 1964

Date of collection Nov. 15, 1963
Ignition Loss Color
Dissolved Solids:
Residue at 180°C
Calculated (Sum) 581
Tons per Acre Foot 0.79
Hardness as CaCO₃ 54
Non-carbonate Hardness 0
T Na 89 SAR 12 pH 7.9
Specific Conductance
(micromhos at 25°C) 912

	epm	ppm
SiO ₂		10
Fe		
Ca	0.95	19
Mg	0.13	1.6
Na		
K		
Na+K	8.86	204
HCO ₃	6.82	416
CO ₃	0.00	0
SO ₄	2.58	124
Cl	0.42	7
F	0.11	2.0
NO ₃	0.01	0.7
	9.94	

Provisional records, subject to revision.

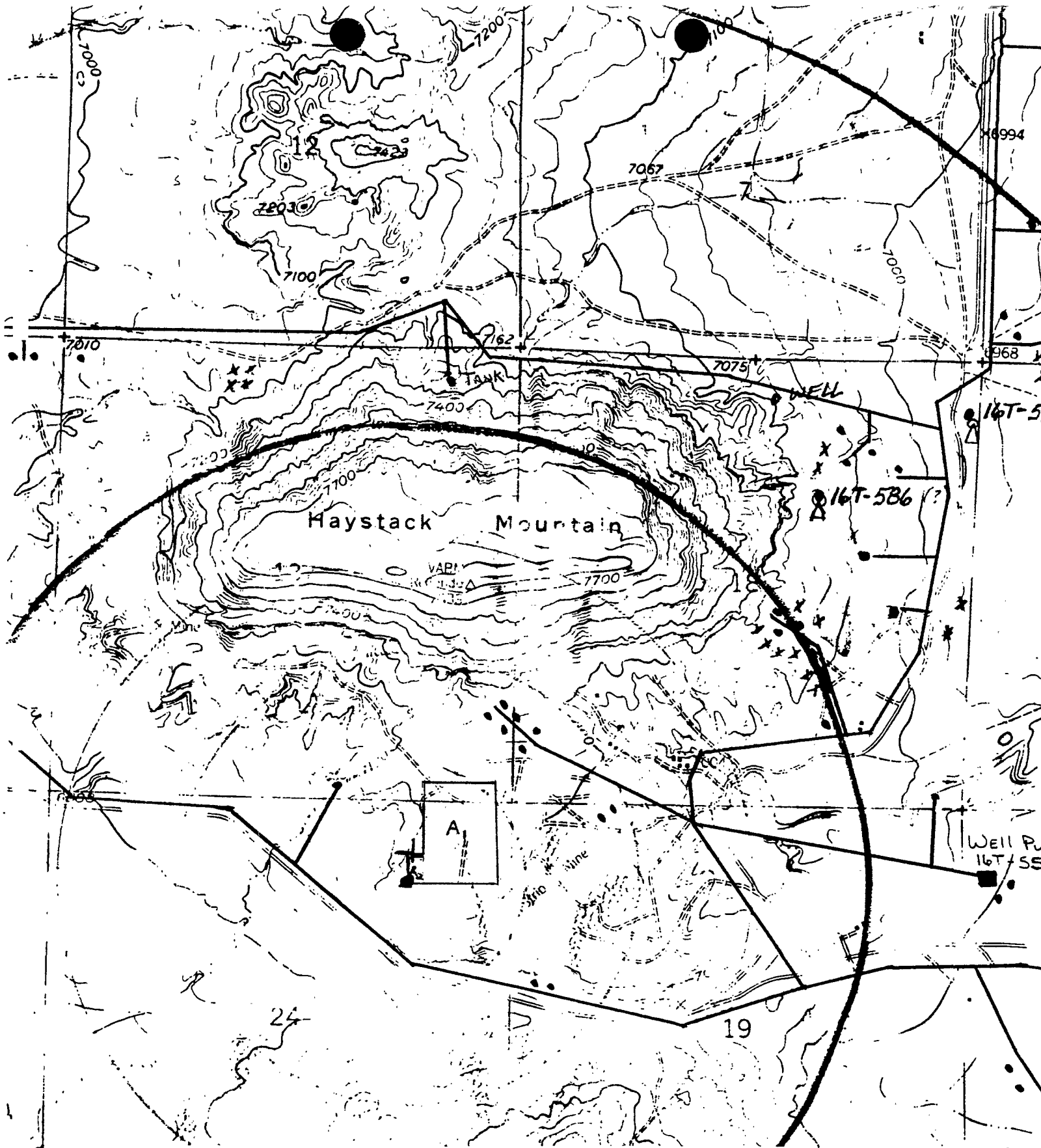


REFERENCE #17

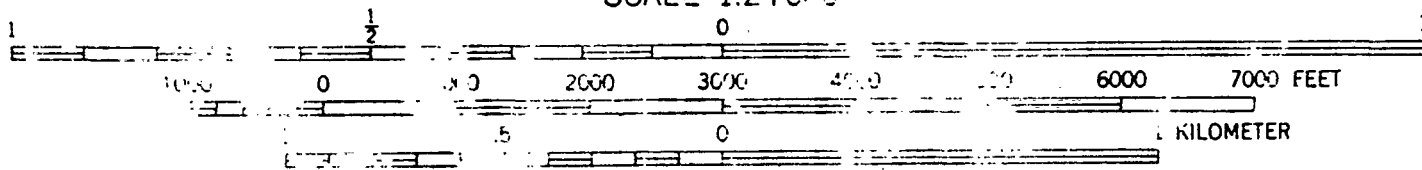
NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90



SCALE 1:24 000



CONTOUR INTERVAL 20 FEET

UPGRADIENT DRAINAGE CALCULATIONS

$$\begin{aligned}A_1 &= L \times W \\&= 818.2 \text{ ft} \times 1181.8 \text{ ft} \\&= 966948.76 \text{ ft}^2 \div 43,560 \text{ ft}^2/\text{acre} \\A_1 &= 22.2 \text{ acres}\end{aligned}$$

$$\begin{aligned}A_2 &= L \times W \\&= 181.8 \text{ ft} \times 363.6 \text{ ft} \\&= 66102.48 \text{ ft}^2 \div 43,560 \text{ ft}^2/\text{acre} \\A_2 &= 1.5 \text{ acres}\end{aligned}$$

$$\text{Total Area} = A_1 + A_2 = 23.7 \text{ acres}$$

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ABANDONED URANIUM MINE

T. MORRIS

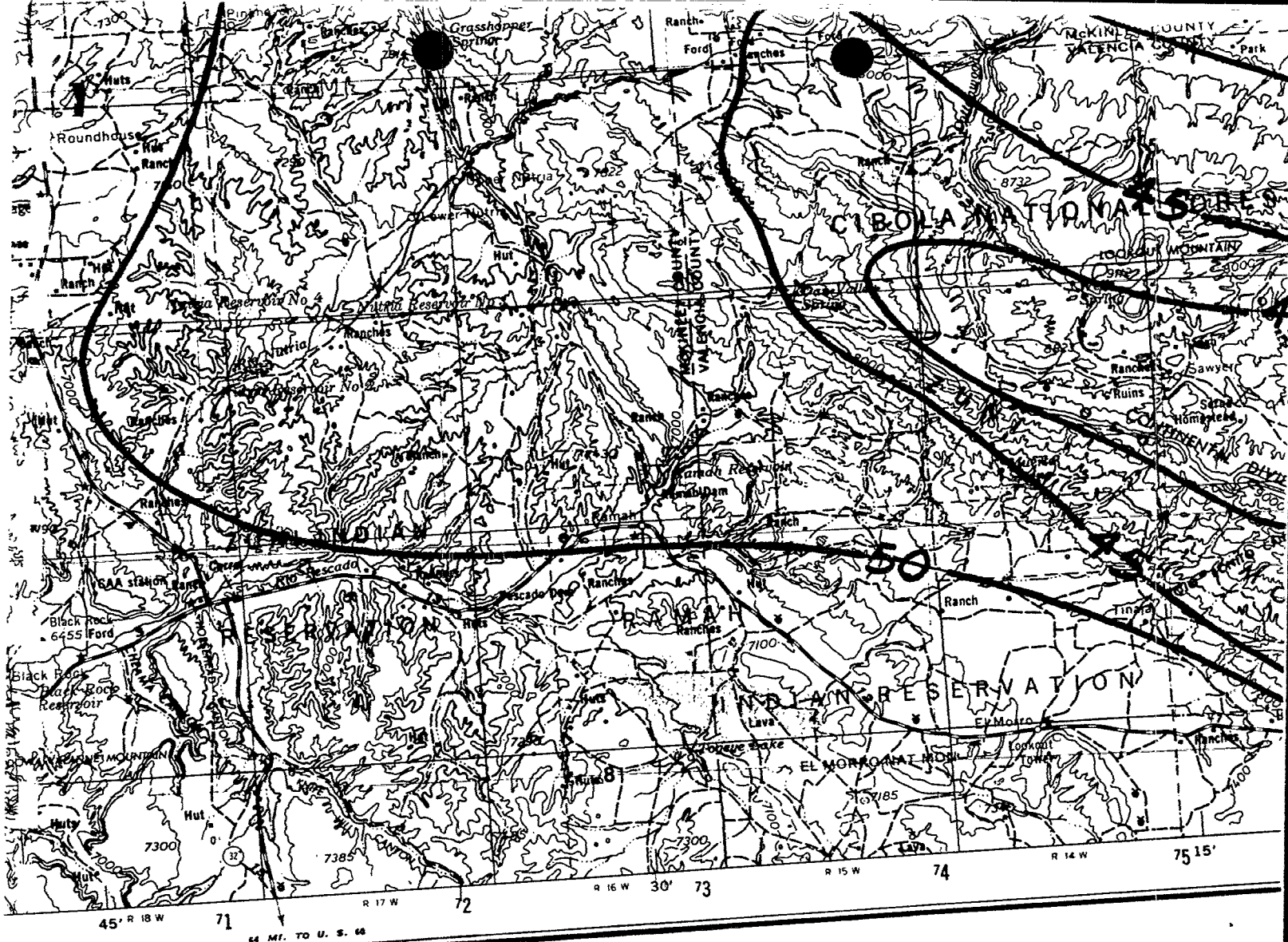
JUNE 1990

REFERENCE #18

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90



20 Statute Miles
K meters
Miles

114°
38°
ESCALANTE, N.J.
CEDAR CITY, UTAM
NJ 12-7
NJ 12-10
NJ 12

GRAND CANYON
NI 12-1
ARIZONA
WILLIAMS

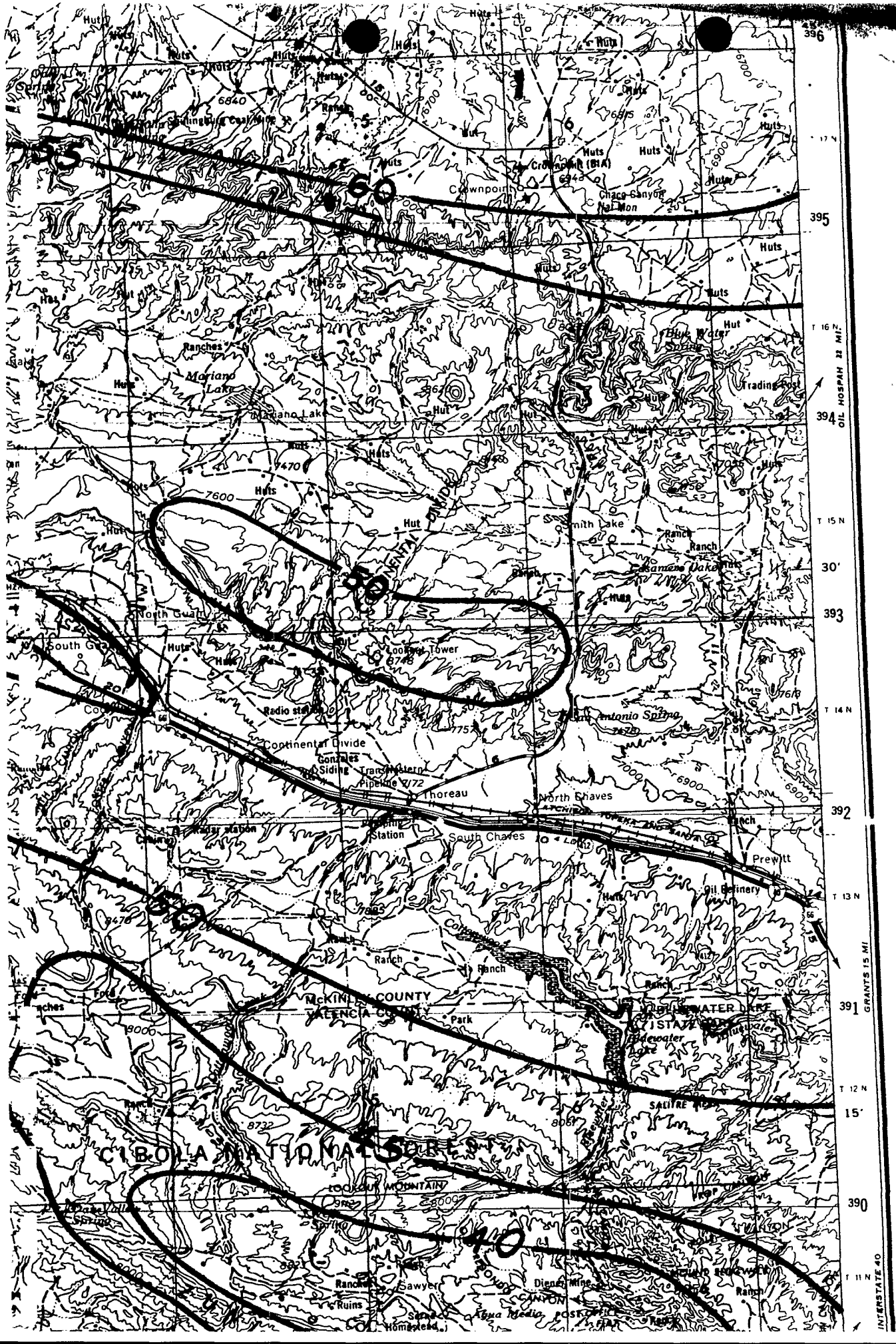
PRESCOTT NI 12-4	FLAESTAFF NI 12-5	NI 12-6 ST. JOHNS	ALBUQUERQUE NI 13-4 FT. SUMNER
NI 12-7 PHOENIX	NI 12-8 MESA	NI 12-9 CLIFTON	NI 13-8 ROSWELL

PRELIMINARY AVERAGE ANNUAL LAKE EVAPORATION FOR
THE NAVAJO RESERVATION IN INCHES OF WATER

ROBERT BECKER, 1985.

19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

TOWNSHIP OR RANGE LINE
LAND GRANT BOUNDARY



Site

GRANTS 15 MI
INTERSTATE 40

REFERENCE #19

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

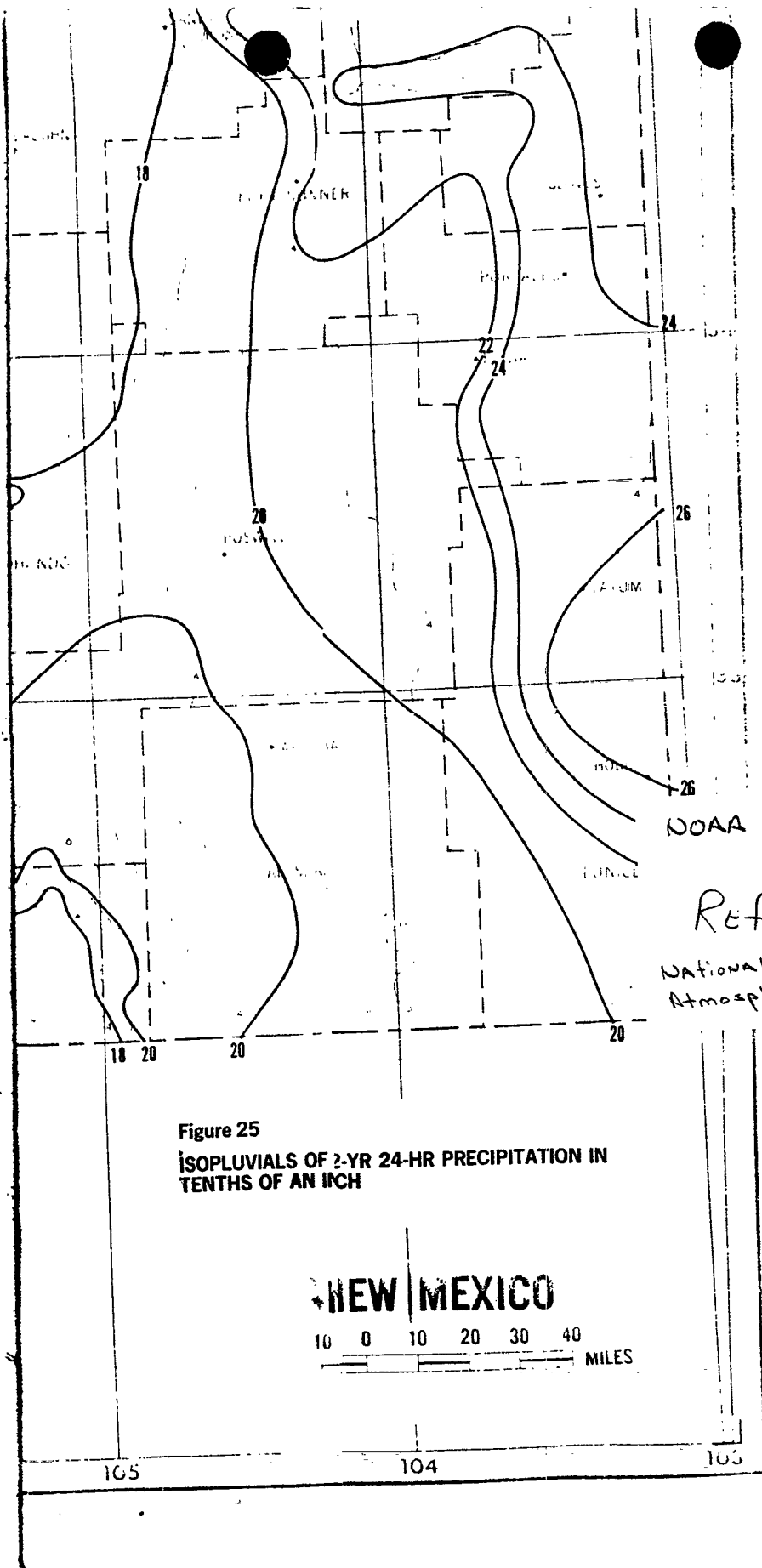
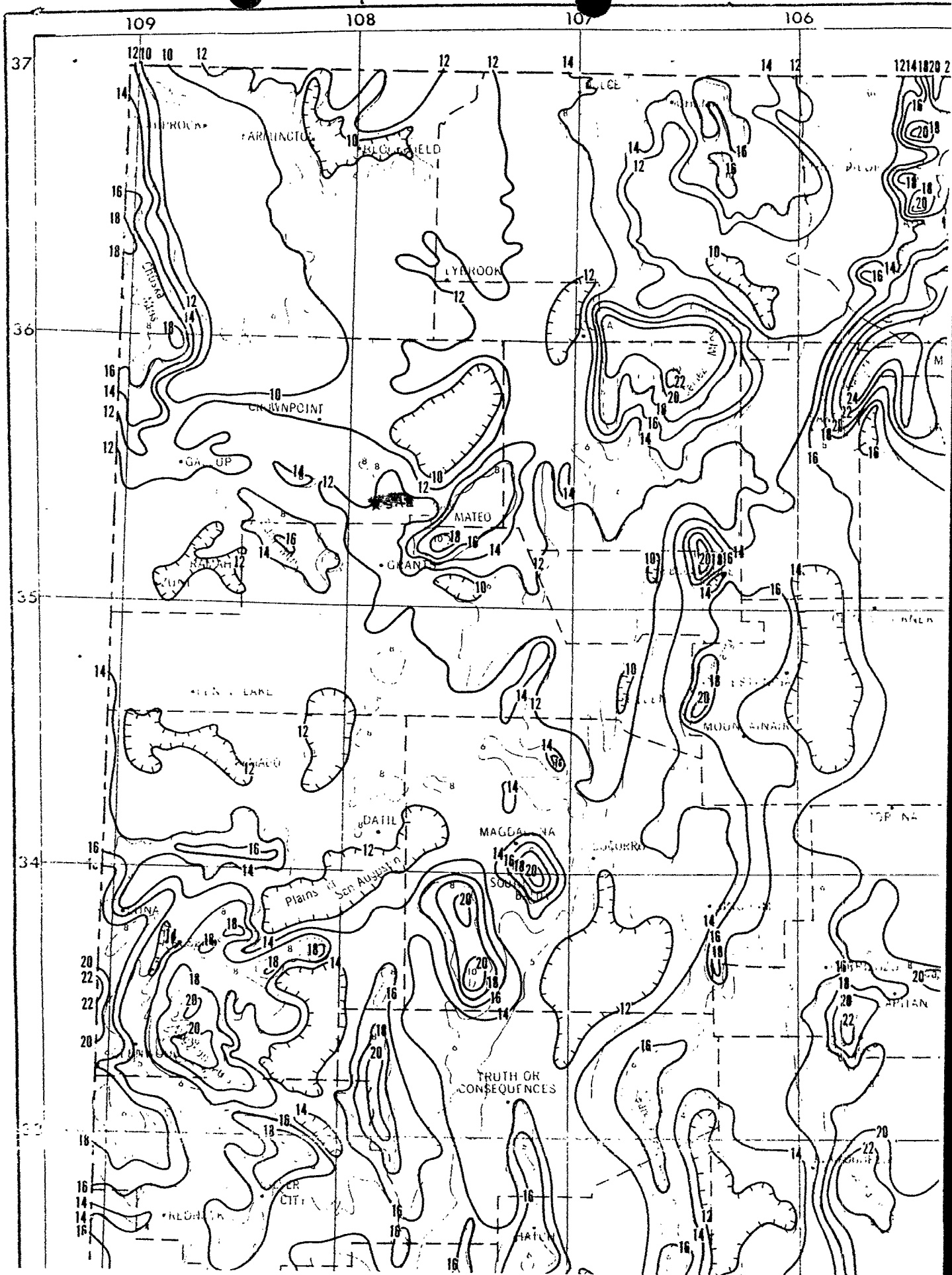


Figure 25
ISOPLUVIALS OF 2-YR 24-HR PRECIPITATION IN
TENTHS OF AN INCH

NOAA Atlas 2,
Volume IV
Ref 19
NATIONAL OCEANIC AND
ATMOSPHERIC
ADMINISTRATION

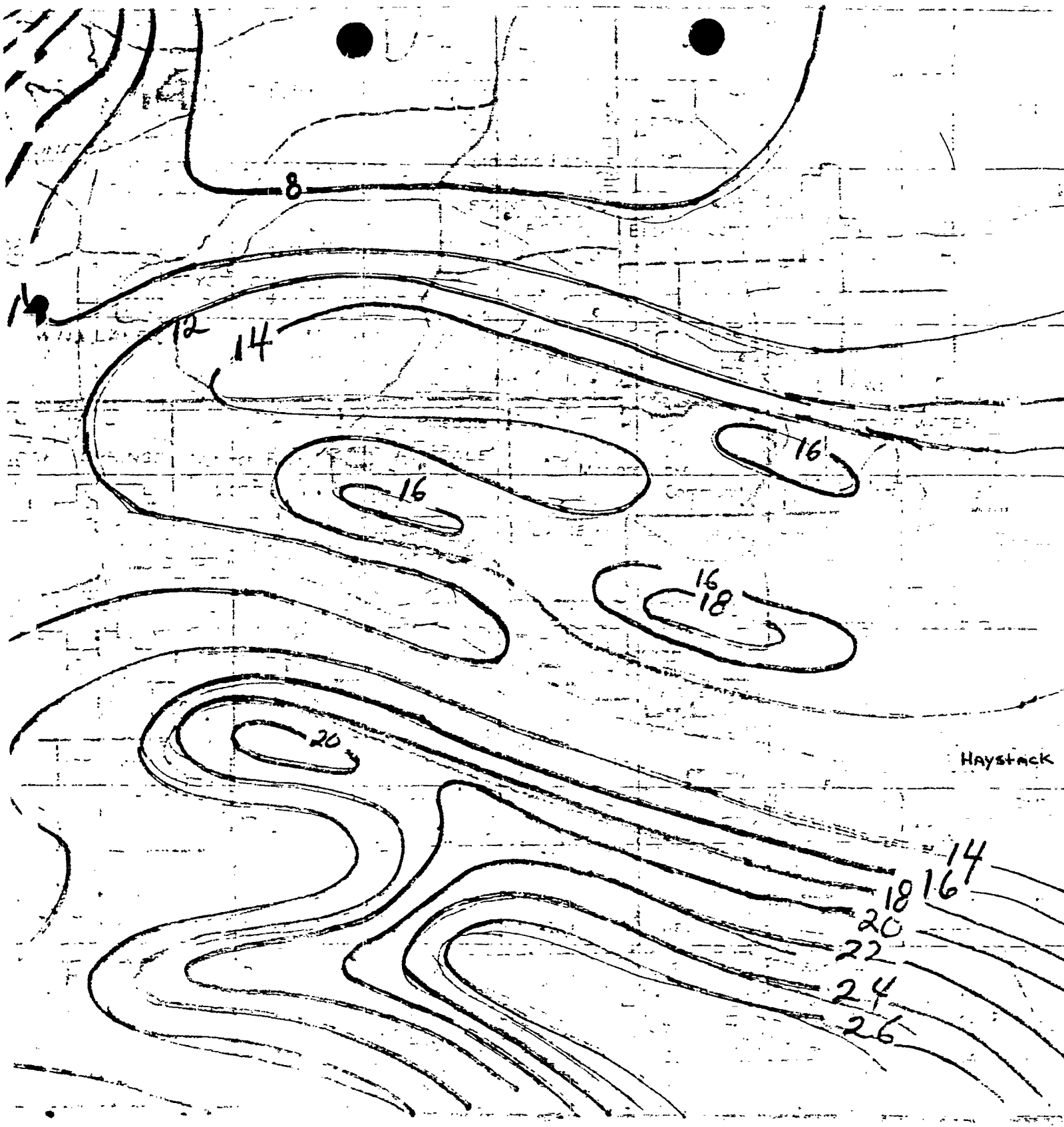


REFERENCE #20

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

AVERAGE
ANNUAL
Rain / Snow (inch)
FOR THE
NAVAJO NATION



Haystack

1" = 6.7 miles



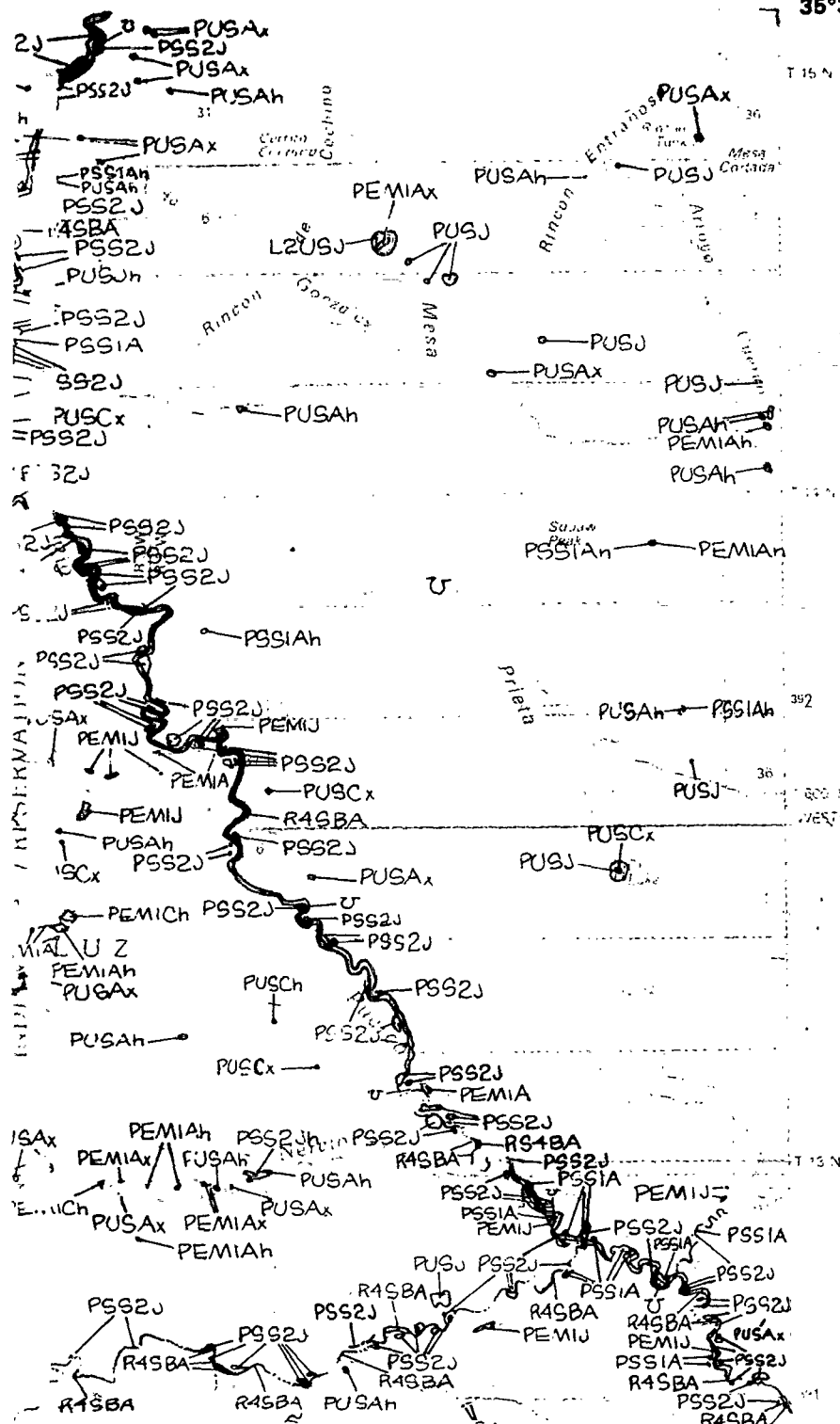
REFERENCE #21

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

30 X 60 MINUTE SERIES (WETLANDS)

107°00'
35°30'



Grants NEW MEXICO

1:100 000 — Scale Map of National Wetlands Inventory



- Wetland classifications
- Highways, roads and other manmade structures
- Water features
- Geographic names



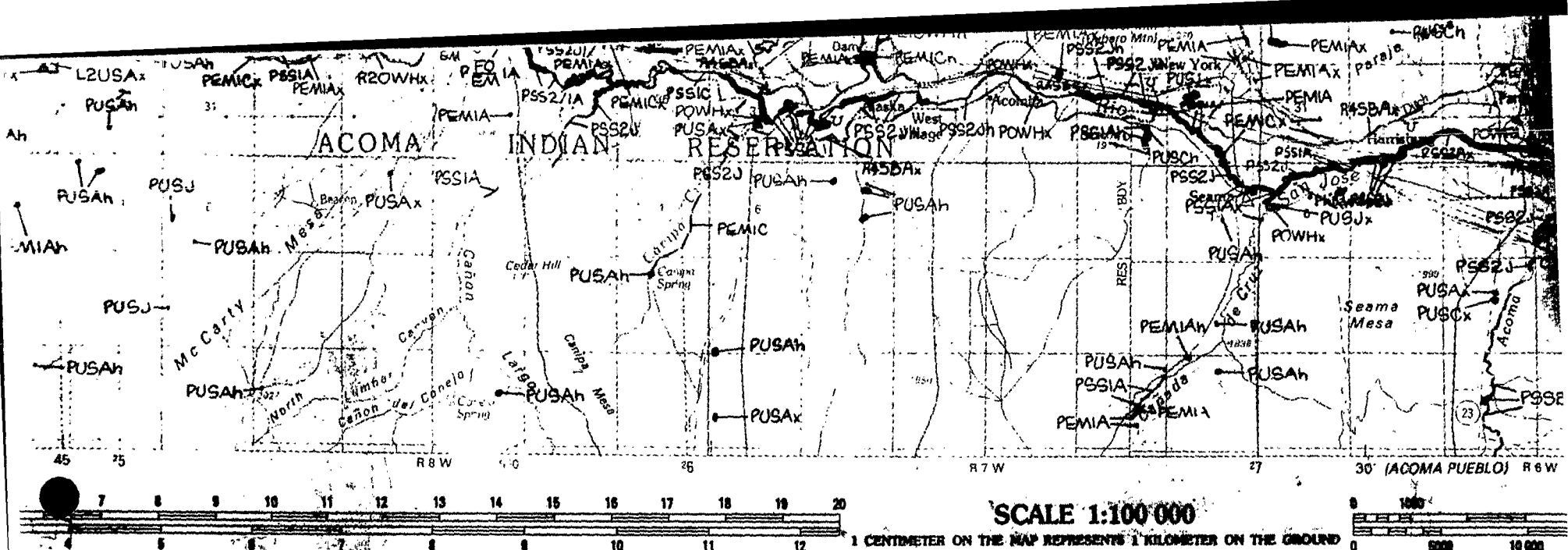
FISH & WILDLIFE

1984

Produced by the United States Fish and Wildlife Service
Wetland classifications from 1:58,000 scale color infrared photographs taken 1981 and other source data.

Projection and 10,000 meter, zone 12
Universal Transverse Mercator
or any other data based on New Mexico corner

[illegible]



E - ESTUARINE																												
1 - SUBTIDAL						2 - INTERTIDAL																						
US - UNCONSOLIDATED SHORE		RS - ROCK BOTTOM		UB - UNCONSOLIDATED BOTTOM		AB - AQUATIC BED		RF - REEF		OW - OPEN WATER/ Unknown Bottom		AS - AQUATIC BED		RF - REEF		SB - STREAMBED		RS - ROCKY SHORE		US - UNCONSOLIDATED SHORE		EM - EMERGENT		SS - SCRUB-SHrub		FO - FORESTED		
1 Cobble-Gravel		1 Bedrock		1 Cobble-Gravel		1 Algal		1 Mollusc		1 Open Water/ Unknown Bottom		1 Algal		1 Mollusc		1 Cobble-Gravel		1 Bedrock		1 Cobble-Gravel		1 Perennial		1 Broad-Leaved		1 Broad-Leaved		1 Broad-Leaved
2 Sand		2 Rubble		2 Sand		2 Rooted Vascular		2 Worm				2 Rooted Vascular		3 Worm		2 Sand		2 Rubble		2 Sand		2 Nonperennial		2 Deciduous		2 Deciduous		2 Deciduous
3 Mud				3 Mud		3 Floating Vascular						3 Floating Vascular				3 Mud				3 Mud				3 Broad-Leaved		3 Broad-Leaved		3 Broad-Leaved
4 Organic				4 Organic		4 Unknown Submerged						4 Unknown Submerged				4 Organic				4 Organic				4 Broad-Leaved		4 Broad-Leaved		4 Broad-Leaved
						5 Unknown Surface						5 Unknown Surface												5 Broad-Leaved		5 Broad-Leaved		5 Broad-Leaved
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REFERENCE #22

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N A T I O N

QUATERNARY

CRETACEOUS

Dashed where approximately located or indefinite

90 D ~ 28 44 ? ...
U

Showing dip, where measured, and amount of displacement in feet, where measured. ~ indicates approximate displacement. Dashed where approximately located; dotted where concealed; queried where position or existence in doubt. U, upthrown side; D, downthrown side

Ring fault or series of concentric ring faults. Interior strata are displaced downward

9

Strike and dip of beds

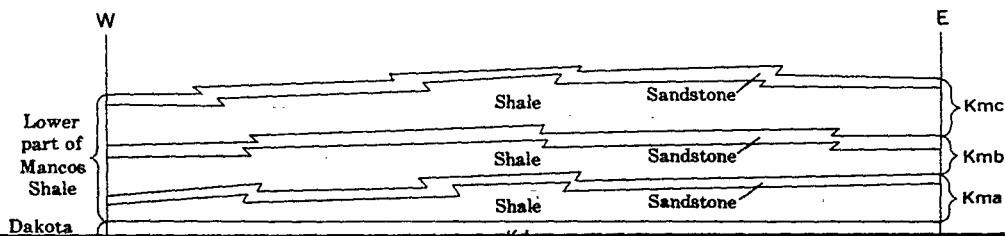
 Inclined Vertical

Strike and dip of joints

9000

Drawn on base of Dakota Sandstone. Short dashed where projected above ground surface. Contour interval 100 feet. Datum is mean sea level.

Uranium mines



107°52'30"
35°22'30"

LAMBROSIA LAKE

EXPLANATION

Qt
Talus and landslide blocks

Qal
Alluvial deposits

Qd
Dune sand

Pleistocene or Recent

QUATERNARY

El Tintero cinder cone
Basaltic cinder and small amounts of ash, lapilli, and bombs

Qbt
Basalt flows from El Tintero
Data from drill holes indicate at least 5 separate flows, aggregating 122 feet in thickness, are present in southwestern part of quadrangle

UNCONFORMITY

Kms
Lower part of Mancos Shale
Gray sandy shale; top eroded; about 20 feet remaining

Upper Cretaceous
Lower Cretaceous

CRETACEOUS

Dakota Sandstone
Pale-yellowish-brown, moderate-orange, and light-gray fine- and medium-grained sandstone; interbedded lenticular dark-gray shale and coal beds near base. 50 to 100 feet thick

UNCONFORMITY

Jmb
Morrison Formation
Jmb, Brushy Basin Member; grayish-green mudstone with minor lenticular light- and yellowish-gray fine- and medium-grained sandstone. 45 to 100 feet thick

Jmw, Westwater Canyon Member; light-, yellowish-, and reddish-gray fine- and medium-grained sandstone; minor light-greenish-gray lenticular mudstone. 125 to 185 feet thick

Jmwu, upper part (Poison Canyon sandstone of economic usage), as much as 80 feet thick, separated from lower part (Jmwl) by mudstone tongues and lenses as much as 25 feet thick, which have the same characteristics as the Brushy Basin Member (Jmb). Mudstone mapped with upper part

Cow Springs Sandstone
Moderate-orange-brown and pale-pinkish-brown fine-grained cross-bedded eolian sandstone. Wedges out to east in north-central part of quadrangle. 0 to 150 feet thick

12

20

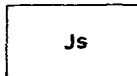
6

lenses as much as 25 feet thick, which have the same characteristics as the Brushy Basin Member (Jmb). Mudstone mapped with upper part (Jmw), lower part; as much as 115 feet thick Jmr, Recapture Member; interbedded variegated claystone, pale-green, brown, red, and purple siltstone, and white, pale-yellow, green, and brown sandstone. 125 to 245 feet thick. Lower part deposited against wedge of Cow Springs Sandstone



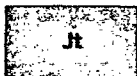
Bluff Sandstone

White and pale-orange fine-grained crossbedded sandstone. 110 to 125 feet thick



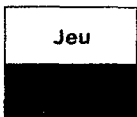
Summerville Formation

Interbedded variegated mudstone, siltstone, and fine- to very fine-grained sandstone. About 175 feet thick



Todilto Limestone

Pale-olive-gray, dark-olive-brown, and pale-yellow limestone, thick bedded, mostly recrystallized in top part, crinkly bedded in middle part, and platy bedded at base. 25 to 35 feet thick



Entrada Sandstone

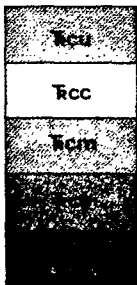
Jeu, upper sandy member; moderate-brown fine-grained crossbedded sandstone. 135 to 140 feet thick Jem, medial silty member; grayish-red-brown calcareous siltstone. 45 to 50 feet thick

UNCONFORMITY



Wingate Sandstone

Moderate-brown to moderate-reddish-orange medium-grained crossbedded sandstone. Base not exposed. About 120 feet thick



Chinle Formation

Rcu, upper member; dark-purplish-red and pale-bluish-gray limy siltstone interbedded with olive-gray to dark-greenish-gray silty limestone in upper 180 feet; reddish-brown even-bedded siltstone in lower 150 feet. Total thickness 330 feet

Rcc, Correo Sandstone Member; pale-grayish-red fine-grained crossbedded arkosic sandstone and minor interbedded gray to pale-brown pebble conglomerate. About 75 feet thick

Rcm, middle member; reddish-brown even-bedded siltstone. About 400 feet thick

Rcs, Sonsela Sandstone Bed of Petrified Forest Member; white, pale-yellowish-brown, yellow, and brown conglomeratic sandstone interbedded with white, blue, purple, and brown claystone. 200 feet thick

Upper Jurassic

JURASSIC

Upper Triassic

TRIASSIC

purple and brown claystone. 290 feet thick.
Tcl, lower member; variegated clayey and sandy siltstone interbedded with lenticular white, yellow, purple, and brown crossbedded conglomeratic sandstone. About 300 feet thick

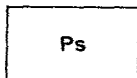
UNCONFORMITY



Moenkopi Formation

Pale-reddish-brown and grayish-red arkosic and micaceous sandstone interbedded with lenticular pebble conglomerate and layers of mudstone galls; cross-bedded near top, even-bedded near base. About 26 feet thick

UNCONFORMITY



San Andres Limestone

Grayish-yellow and brown to red dense limestone interbedded with yellow fine- to medium-grained cross-bedded to structureless sandstone in upper part, 80 feet thick; yellow sandstone similar to that above in middle part, 15 feet thick; dense gray limestone with streaks and zones of coarse-grained calcite in lower part, 20 feet thick. Upper surface karst. Total thickness 115 feet

PERMIAN

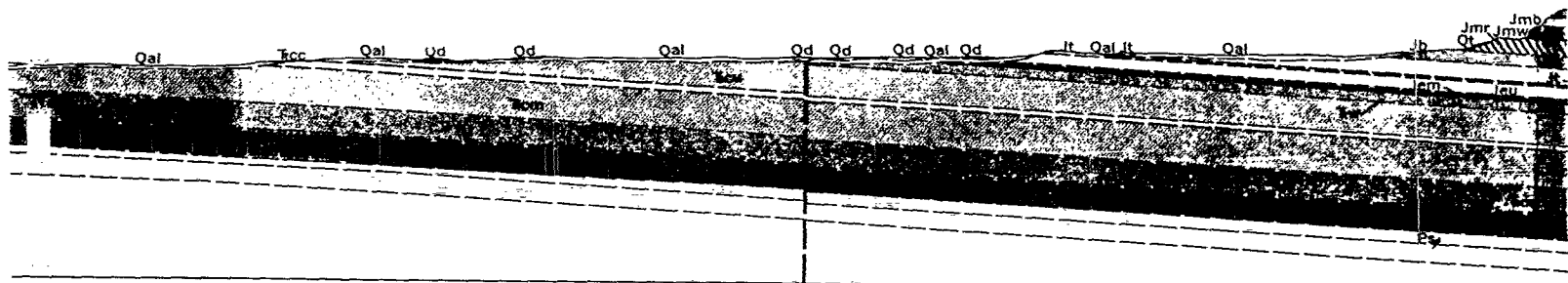
Lower and Middle(?)
Triassic

TCS

5600

35°15'
107°52'30"

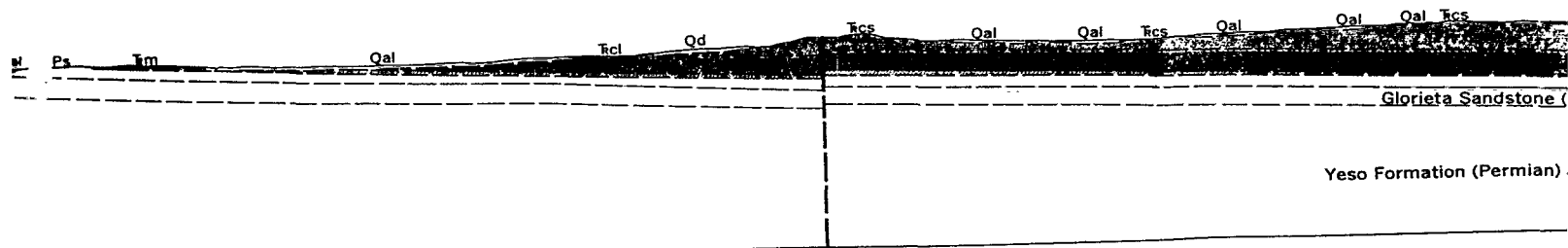
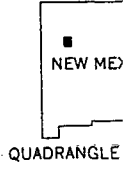
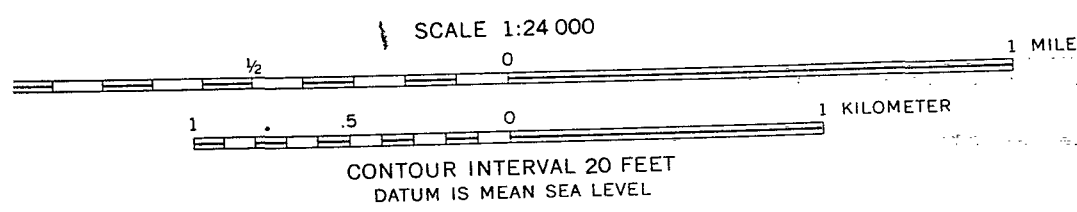
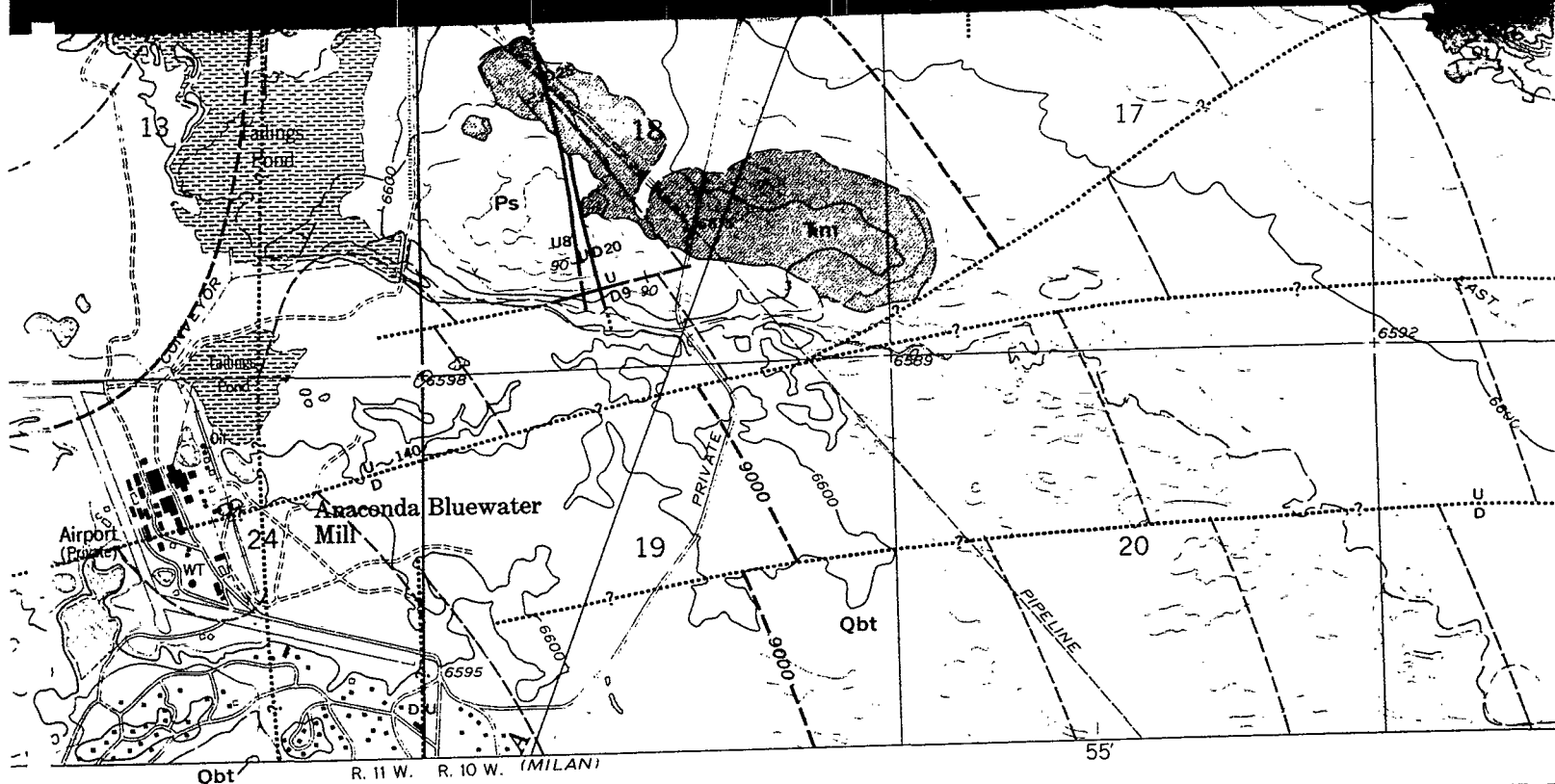
5E 58 (GRANTS)



INTERIOR—GEOLOGICAL SURV

ND McKINLEY COUNTIES, NEW MEXICO

stone; minor light-greenish-gray lenticular mudstone. 125 to 185 feet thick
Jmwu, upper part (Poison Canyon sandstone of economic usage), as much as 80 feet thick, separated



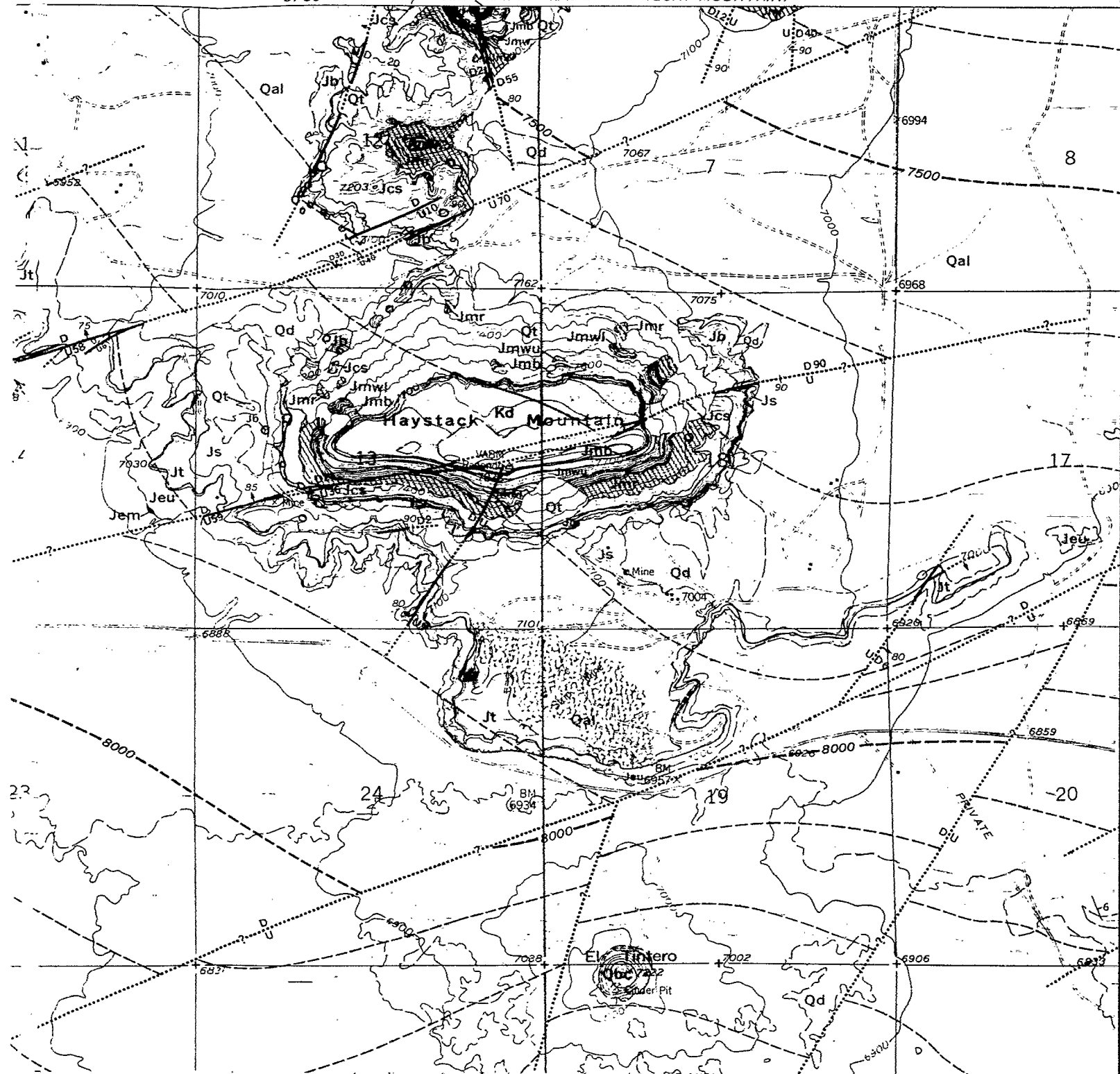
GEOLOGIC MAP OF THE BLUEWATER QUAD

Roll

57°30"

Jmr Kma R. 11 W. R. 10 W.

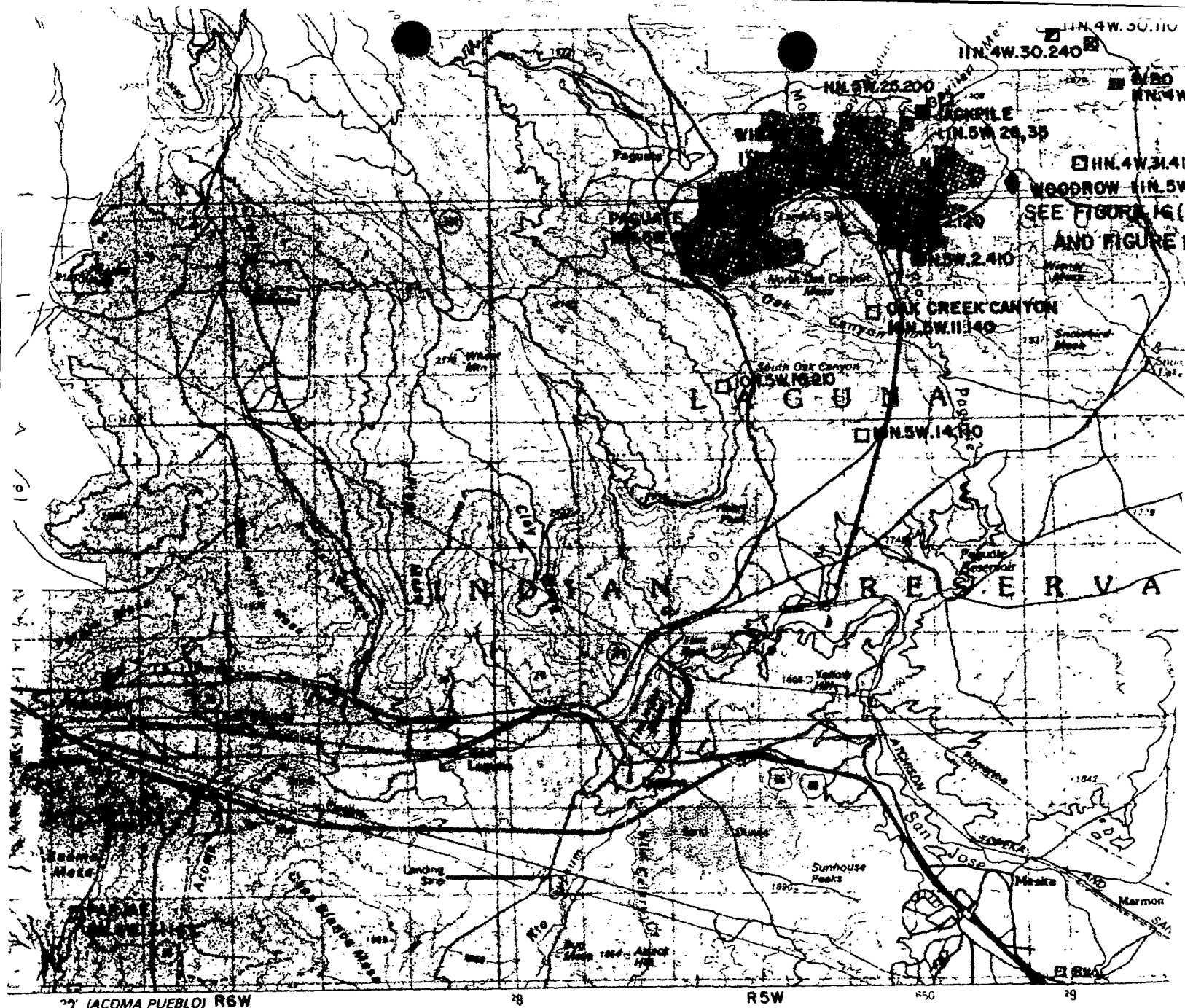
(GOAT MOUNTAIN)



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SCALE 1:100 000

5	6	7	8	9	10
METERS					
2	3	4	5		
MILES					
10000	15000	20000	25000		
FEET					

NEW MEXICO

QUADRANGLE LOCATION

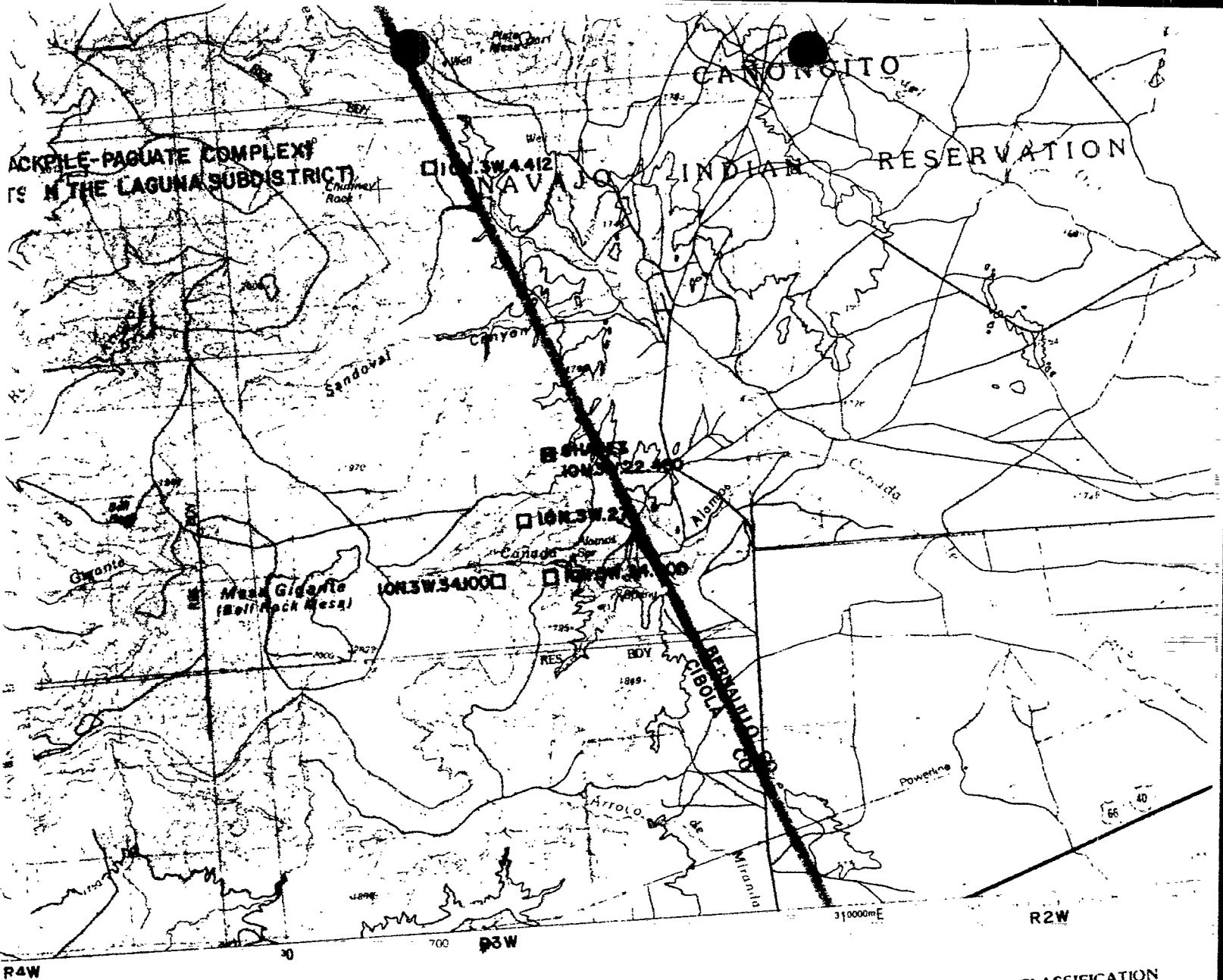
MAP INTERVAL 50 METERS

VERTICAL DATUM OF 1929

THE GRANTS 30- BY 60-MINUTE QUADRANGLE, MCKINLEY, CIBOLA

LOCATION OF SYMBOLS IN TABLE 1-1 AND FIGURE 1.

PHIL. MAPS AND SYMBOLS AVAILABLE ON REQUEST



LEGEND

- Perennial stream, lake
- Intermittent stream, lake
- Village or locality
- Landmark structure
- Public park or recreation area
- Forest or game land area
- Other public area or Military or Indian reservation

ROAD CLASSIFICATION

- Primary highway, hard surface
- Secondary highway, hard surface
- Light-duty road, hard or improved surface
- Street or unimproved road
- Trail
- Interstate route
- U.S. route

GRANTS, NEW MEXICO

NW 4 ALBUQUERQUE NEW MEXICO

N3500-W1070

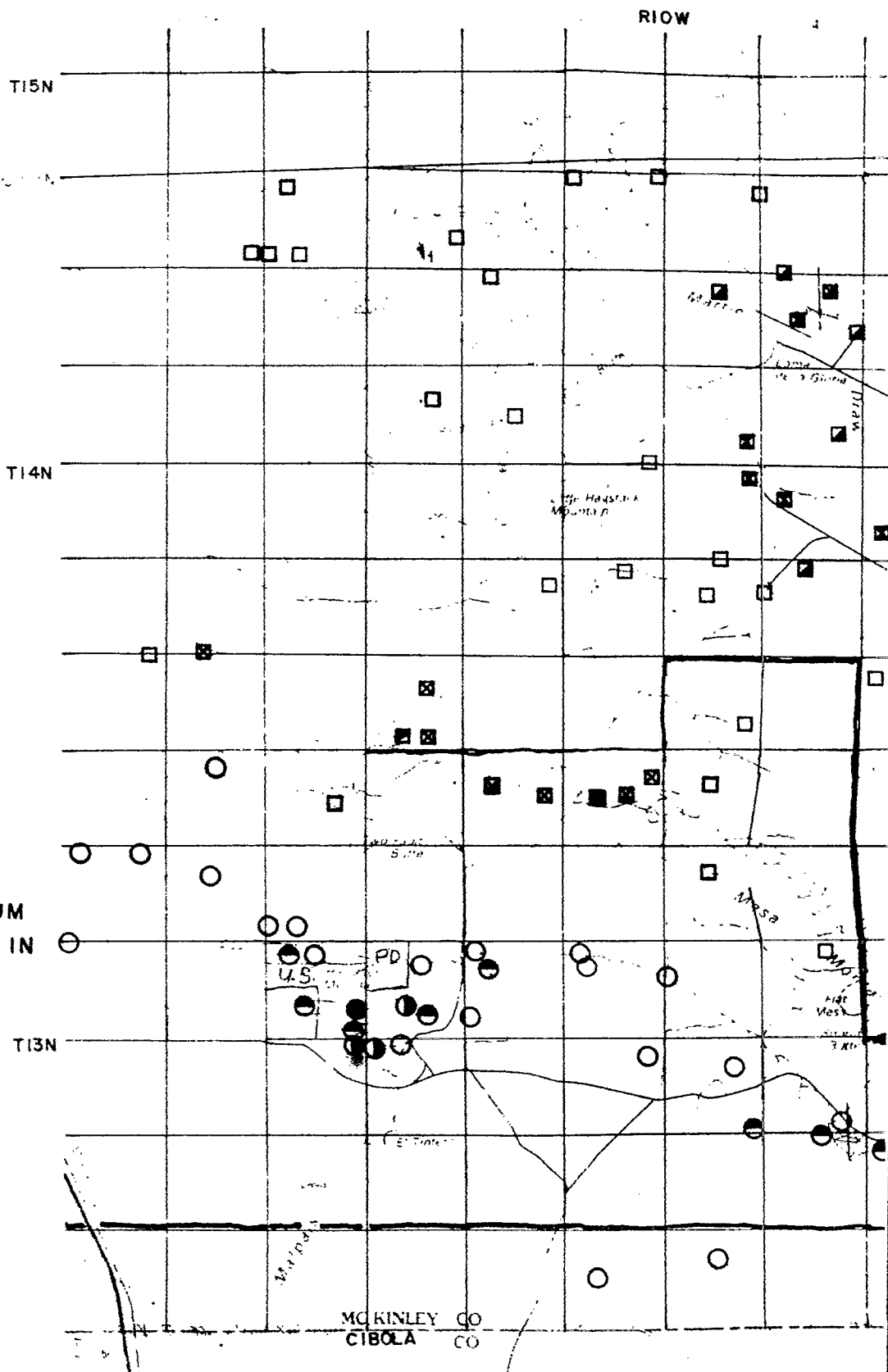
197

UNITED STATES

PRODUCTION CATEGORY	CLASS	DEPOSITS IN IGNEOUS AND METAMORPHIC ROCKS	DEPOSITS IN VOLCANIC ROCKS	SANDSTONE DEPOSITS	DEPOSITS IN OTHER SEDIMENTARY ROCKS	DEPOSITS OF UNCERTAIN ORIGIN
OCCURRENCE, NO PRODUCTION		X	△	□	○	◇
UP TO 20,000 POUNDS U_3O_8		⋈	▲	▣	◐	◊
120,000-200,000 POUNDS U_3O_8		⊗		▤	◑	◆
200,000-2 MILLION POUNDS U_3O_8				▥	●	
2 MILLION-20 MILLION POUNDS U_3O_8				▦		
GREATER THAN 20 MILLION POUNDS U_3O_8				■		

TABLE 1-1 - KEY TO SYMBOLS USED ON RADIOMETRIC OCCURRENCE LOCATION MAPS

RIOW









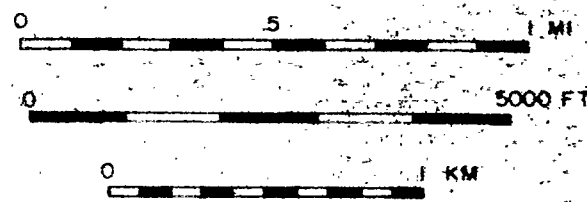
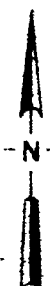
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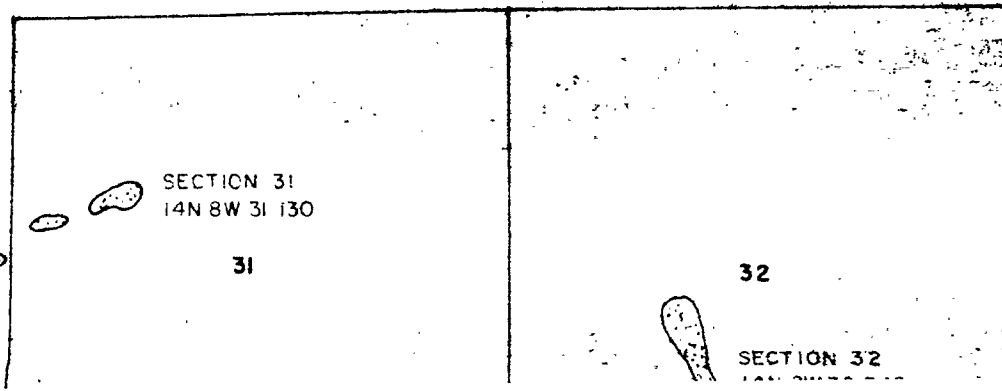
T. MORRIS JUNE '90

**FIGURE 11 - URANIUM ORE DEPOSITS AND
GRANTS URANIUM DISTRICT, N
COMPILED BY V.T. MCLEMORE FROM FIELD
UNPUBLISHED DATA, NMBMMR UNPUBLISHED
SMITH AND PETERSON (1980), HAZLETT
SANTOS (1963), AND CLARY AND OTHERS
AVAILABLE.)**

-  INCLINED SHAFT
-  SHAFT
-  ADIT
-  X OPEN PIT
-  ORE BODIES IN ANY STRATIGRAPHIC
HORIZON, APPROXIMATE BOUNDARIES
-  DRILL HOLE



ON 36
W 36 422



12

HAY STACK

13N 11W 13.114

HAYSTACK

BUTTE

18

HAYSTACK

13N 11W 13.314

HAYSTACK

13N 11W 13.324

SECTION 18

13N 10W 18.341

HAY STACK

13N 11W 13.314

HAYSTACK OPEN PIT

13N 10W 18.120

SECTION 24

13N 11W 24.222

24

19

20

R11W R10W

REFERENCE #25

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OPEN DIRT

O.F.R.
183

[illegible]

100-20491

1990

1. 1. Name of the person or organization
2. 2. Address
3. 3. City
4. 4. State
5. 5. Zip
6. 6. Phone
7. 7. Fax
8. 8. E-mail
9. 9. Other

Uranium and Thorium Occurrences in New Mexico:
Distribution, Geology, Production, and Resources,
with Selected Bibliography

by

Virginia T. McLemore
New Mexico Bureau of Mines and Mineral Resources
Open-file Report OF-183

September, 1983

NAVAJO SUPERFUND OFFICE
P.O. BOX 2946
WINDOW ROCK, AZ. 86515

Partial Financial Support by
U.S. Department of Energy
Grand Junction Area Office
Subcontract No. 82-555-E

Uranium and Thorium Production in New Mexico

Uranium production in New Mexico has surpassed yearly production from all other states since 1956 (U.S. Department of Energy, Statistical data of the uranium industry, 1969 to 1982). Over 200 mines (Appendix 3) in New Mexico have produced 162,010 tons (146,973 metric tons) of U_3O_8 from 1948 to 1982, 40% of the total United States uranium product (Table 3). Over 99% of this production has come from sedimentary deposits in the Grants uranium district in northwestern New Mexico. Uranium production also has come from sandstone, vein-type, hydrothermal-vein, and pegmatite deposits scattered throughout the state (Fig. 1).

From 1948 through 1970, the U.S. Atomic Energy Commission purchased most of the uranium ore produced in New Mexico, although minor amounts of ore may have been sold to chemical companies. Production statistics for individual mines from 1948 through 1970 have been released to the public; these production figures are tabulated in Appendix 3 (Table 3-1). Yearly production figures have been compiled by the U.S. Atomic Energy Commission (AEC) and succeeding agencies, the U.S. Energy Research and Development Administration (ERDA) and the U.S. Department of Energy (DOE); they are tabulated in Table 3. Production by area and host rock is given in Table 4.



FIGURE 3—GEOGRAPHIC PROVINCES IN NEW MEXICO

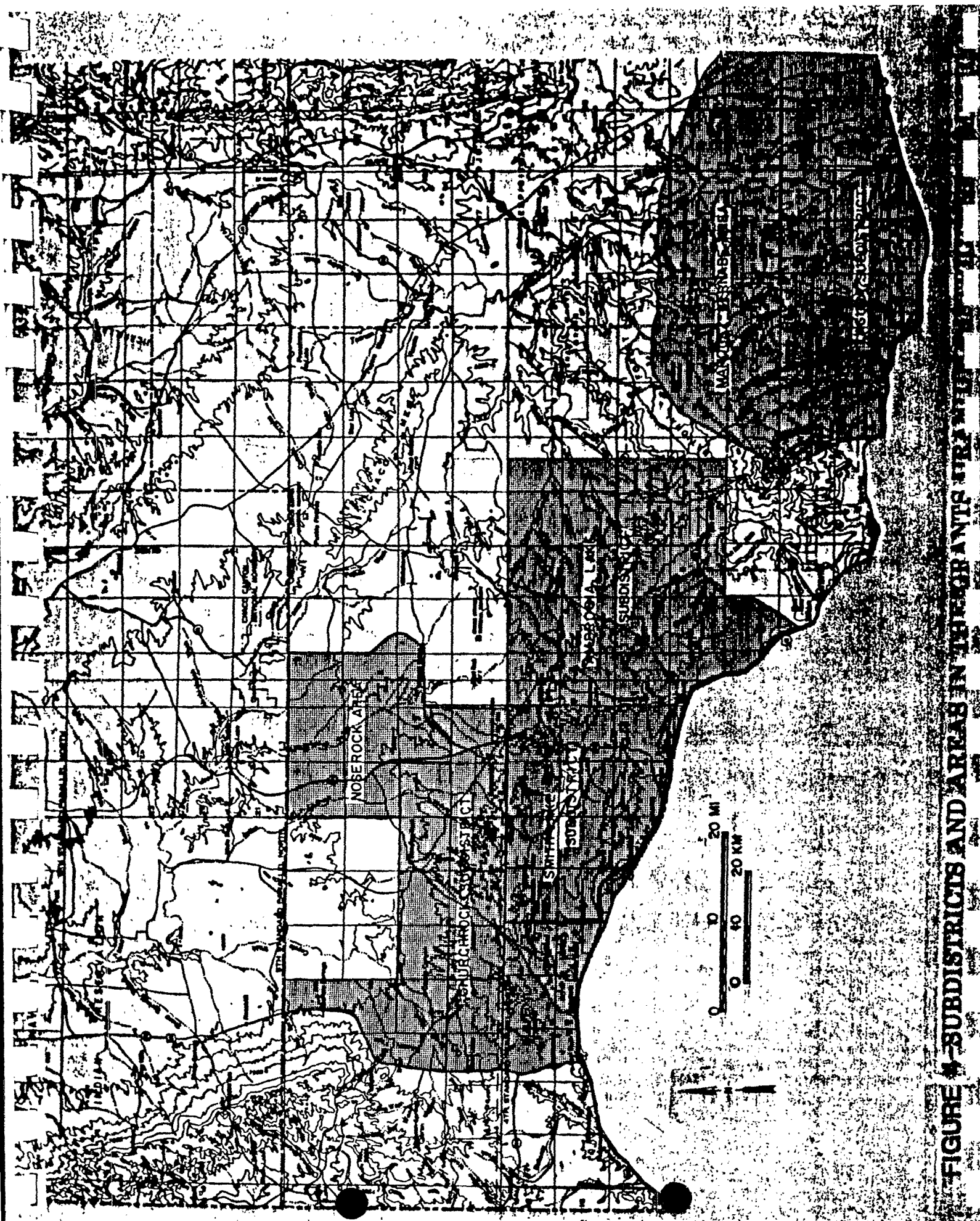


FIGURE 4-SUBDISTRICTS AND AREAS IN WHICH ANTIS FIRE ANT

Juan Basin; Monte Largo Hills, Bernalillo County; Lincoln County; Burro Mountains, Grant County; Rio Grande area, Socorro and Sierra Counties; and Cornudas Mountains, Otero County (Fig. 5). No thorium has been produced in New Mexico except possibly as a by-product of production from pegmatites.

Over 1,300 uranium and thorium occurrences are individually described in Appendix 1 and located in Figure 1 and various county maps (Figs. 1-5 to 1-33). Uranium prospects, deposits, and mines in the Grants uranium district are located on 30- by 60-minute maps (Figs. 6-9) and additional district maps are included (Figs. 11-13). Uranium occurrences in areas outside of the Grants uranium district are plotted on additional maps as indicated.

Limestone Deposits in the Jurassic Todilto Limestone and Adjacent Units

Over 100 uranium occurrences are found in the Jurassic Todilto Limestone (Appendix 1), 42 of which have produced ore (Appendix 3). Over 6,736,000 pounds (3,055,000 kilograms) of uranium have been produced from the Todilto Limestone and adjacent units from 1950 to 1982, about 2% of the total uranium production in New Mexico (Table 4). The majority of these occurrences are in the Grants uranium district, although minor occurrences are found in the Chama Basin-Llaves area in Rio Arriba County, Nacimiento Mountains in Sandoval County, and the Sanostee subdistrict of the Shiprock district in San Juan County. Two occurrences, Reed Henderson #1 in the Sanostee subdistrict

and Box Canyon in the Chama Basin (Appendix 3), have produced minor quantities of uranium ore in the 1950's. Although the bulk of this mineralization occurs in the Todilto Limestone, minor mineralization occurs also in the basal portion of the overlying Summerville Formation and at the top of the underlying Entrada Sandstone (Fig. 10).

The initial discovery of uranium mineralization in the Grants uranium district was in 1950 by Paddy Martinez in the Todilto Limestone. Uranium minerals were known to occur in the Todilto Limestone since the early 1920's (Melancon, 1963) and in 1948 (C. T. Smith, 1954), but their significance was not realized until Paddy Martinez's discovery. Paddy Martinez discovered tyuyamunite at what is now known as the Haystack-Section 19 mine.

The Todilto Limestone consists of two informal units, a basal limestone and an upper gypsum-anhydrite member. The basal limestone is 5-30 ft (1 to 9 m) thick and present everywhere in the Todilto depositional basin. This unit consists of three zones, a basal platy or laminated zone, a crinkly or crenulated zone, and an upper massive zone. The overlying gypsum-anhydrite member reaches a maximum thickness of 170 ft (32 m) and is present in the central portions of the Todilto basin. The gypsum-anhydrite member is locally mined and constitutes much of the gypsum and anhydrite resources in New Mexico (G. S. Austin and others, 1982). The gypsum-anhydrite member is present in the Laguna area, but is absent elsewhere in the Grants uranium district. However, this unit is penetrated by drill holes about 8 mi (13 km) north of the Poison Canyon area (Hilpert, 1969, p. 95).

WEST

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CARRIZO
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CHURCH
ROCK

AMBROSIA
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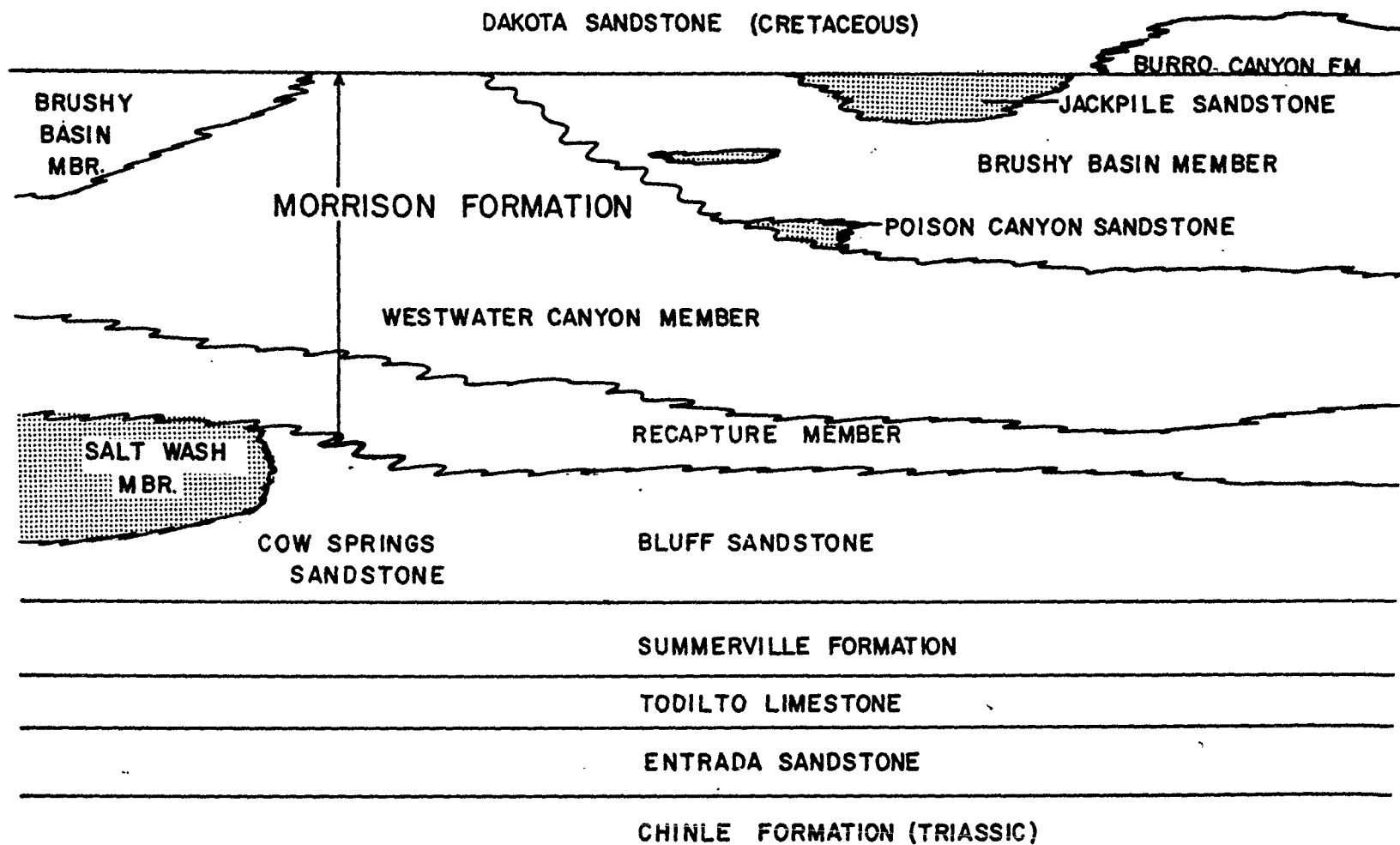


FIGURE 10-STRATIGRAPHIC CORRELATIONS IN THE SAN JUAN BASIN.

The Todilto Limestone is deposited in a basin which occupies an area of about 34,000 mi² (88,060 km²) in the San Juan Basin. It is equivalent in age with the Pony Express Limestone Member of the Wanakah Formation in Colorado and the Curtis Formation in Utah (Green, 1982).

The actual depositional environment of the Todilto Limestone is controversial. The Todilto Limestone overlies the Entrada Sandstone, which consists of eolian dune and inland interdune sequences; fluvial units are absent. The overlying Summerville Formation consists of eolian dune and fluvial sabkha sequences. It is uncertain whether the origin of the Todilto Limestone was marine or a nonmarine. The presence of the gypsum-anhydrite member and correlation with marine limestones of the Curtis Formation suggest a marine origin, an embayment or lagoon (Hines, 1976; B. L. Perry, 1963). However, the lack of confirmed marine fossils (Hines, 1976) and of dolomitic sequences (Green, 1982), the presence of varved sequences (R. Y. Anderson and Kirkland, 1960, 1966), and the coastal-continental environments of the Entrada Sandstone and Summerville Formations favor a lacustrine origin, a coastal sabkha environment (Rawson, 1980a, b), an enclosed saline lake, or a brackish-water lake connected to the sea (R. Y. Anderson and Kirkland, 1960). Recent isotopic evidence supports a marine origin (Ridgley and Goldhaber, 1983).

Uranium mineralization is found only where the gypsum member is absent (Hilpert, 1969), and the mineralization may extend into the overlying Summerville Formation or underlying Entrada Sandstone. The majority of the Todilto Limestone deposits are

found along outcrops of the Todilto Limestone in the Poison Canyon and Thoreau areas, although mineralized drill holes in the Todilto Limestone also occur in the Ambrosia Lake area (Young, 1960, p. 270; Irving Rapaport, Four Corners Exploration Company, written commun., 11/11/82; Harlen Holen, U.S. DOE, written commun., 1983). Uranium deposits are tabular and irregular in shape, similar to sandstone deposits. They range in size from a few feet to 100's of feet wide and long and up to 20 ft (16 m) thick. Three types of mineralization are found; unoxidized primary deposits, oxidized primary deposits, and secondary deposits (Gabelman, 1970). Most of the limestone deposits occur along the flanks or axes of intraformational folds, unlike sandstone deposits. Locally, the limestone deposits appear to align in trends subparallel to the sandstone deposits (Fig. 11). Uranium mineralization occurs throughout the entire thickness of the Todilto Limestone. The largest ore bodies occur where the intraformational folds are clustered and have a similar trend (Hilpert, 1969). Pb/U apparent age dates suggest that primary mineralization occurred during or just after deposition of the Todilto Limestone (Berglof, 1969; D. S. Miller and Kulp, 1963).

The origin of the ore-controlling intraformational folds is controversial (Hines, 1976; Hilpert, 1969). These folds are restricted to the Todilto Limestone and to the basal portion of the Summerville Formation; overlying beds are flat-lying. The folds vary in size and shape. They tend to cluster in east-west or north-south trends. Open and closed anticlines (Fig. 14), recumbent folds, and chevron folds (Fig. 15) are common. Their axes show little, if any, relationship to regional structure.

Figure 14 - Intraformational fold in the Todilto Limestone at the Haystack open pit. This fold may have resulted from algal structures. Uranium mineralization is disseminated within the limestone and along the fractures and bedding planes.



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Rapaport and others (1952a, b) and Hilpert and Moench (1960) attribute these folds to soft sediment slumping or creeping down a depositional slope or the flanks of anticlines. Gabelman (1956b) attributes the folds to volumetric changes due to dehydration and diagenesis. B. L. Perry (1963) suggests that the folds are a result of differential loading and compaction near subsiding reef or biohermal structures. Parasitic or drag folds on tectonic features may have produced the intraformational folds (Hines, 1976). However, none of these theories is consistent with all of the field observations (Hines, 1975; Green, 1982).

A theory proposed by Rawson (1980a, b) and Green (1982) and modified by the author is consistent with many of the field observations, but certainly is not the only viable theory possible. The Todilto Limestone was deposited in an arid climate, in an enclosed saline or brackish-water lake; the exact setting of the Todilto basin is not critical to this model. Periodic drying of the lake enabled deposition of the gypsum member. Simultaneously, Summerville dunes slowly migrated over Todilto limey muds and algal mats, compacting and warping the Todilto beds, thereby forming the intraformational folds. Continued migration of Summerville dunes locally continued to deform the underlying Todilto muds; forming convolute laminations, mounds, rolls, folds, and anticlines and synclines (Green, 1982). The presence of a depositional slope basinwards enhanced migration of the Summerville dunes and deformation of the underlying Todilto beds. Hydraulic and evaporative pumping of uraniferous groundwater in the underlying permeable Entrada

Figure 15 - Chevron fold in the Todilto Limestone at the Section 25 open pit. Height of pit wall is approximately 12 ft (3 m).



Sandstone brought the uraniferous waters into the organic-rich layers of the Todilto mud. The intraformational folds acted as a structural trap for uranium-bearing waters. The Todilto mud would be permeable only until the muds dried, therefore this hydraulic pumping occurred in a relatively short period of time. However, as the deformed muds dried and turned into impermeable limestones, they fractured and faulted where folded. These fractures provided the permeability required for additional hydraulic and evaporative pumping to continue after diagenesis. The hydraulic and evaporative pumping could not occur where the gypsum member was deposited, since the gypsum acted as a cap. Subsequent oxidation and remobilization of primary uranium deposits occurred possibly during Tertiary times, as suggested by Saucier (1980).

Additional uranium deposits are likely to occur in the Todilto Limestone in the Grants uranium district (Green and others, 1980b, c; U.S. Department of Energy, 1980). These undiscovered deposits probably will be similar in size and shape to the known Todilto deposits. Numerous holes beyond 1,000 ft (305 m) depths have been drilled in the Ambrosia Lake area. A surprising number of these deep drill holes indicates mineralization in the Todilto Limestone. Additional work is needed to refine the model of Green (1982) and Rawson (1980a, b) and to adequately delineate the margins of the Todilto basin and the extent of the Summerville dunes.

Outside of the Grants uranium district, economic ore deposits in the Todilto Limestone are scarce (Appendix 1).

mine, about 900-1,000 ft (244-305 m) at San Antonio Valley, about 2,100 ft (640 m) at Marquez, and about 1,000-2,500 ft (305-732 m) at Bernabe Montaño. Preliminary studies indicate that most of the mineralization is primary tabular ore and occurs in multiple horizons (S. C. Moore and Lavery, 1980; B. A. Livingston, Jr., 1980; Kozusko and Saucier, 1980).

At Marquez, ore is controlled by shale breaks, high permeability, and recurrence of meandering streams. Where the shale beds are absent, uranium mineralization is dispersed throughout the sandstone and is subeconomic. Mineralized sandstones tend to be permeable; however, excessively permeable sandstones allow mineralization to be redistributed elsewhere. Mudstone pebbles restrict the permeability and concentrate uranium mineralization. Uranium mineralization appears to be restricted to meandering channels within the dominantly braided-stream complex (B. A. Livingston, Jr., 1980). Actual development and mining of these deposits will add to our knowledge of mineralization in this area.

A few minor occurrences are found in the Jackpile sandstone and the Brushy Basin Member near the Rio Puerco mine (Fig. 6). Two minor occurrences are found in Cretaceous coal beds south of the Bernabe Montaño area (Fig. 1). Two beach-placer sandstone deposits occur in the Bernabe Montaño area and will be discussed separately.

Ambrosia Lake Subdistrict

Over 200 uranium occurrences are found in the Ambrosia Lake subdistrict in the Todilto Limestone, Morrison Formation and

Cretaceous sediments (Figs. 7, 8, 11; Appendix 1). Over half of these occurrences are in the Morrison Formation, mostly in the Westwater Canyon member and the Poison Canyon sandstone. More than 50 of these occurrences have produced uranium since the initial sandstone discovery in Poison Canyon in 1951 (Appendix 3). The Blue Peak mine was the first underground uranium mine in the Grants district. The Ambrosia Lake-Mt. Taylor trend (Fig. 11) is the largest mineralized area in the Grants district and accounts for substantial portion of the reserves and potential resources in New Mexico (McLemore, 1981; U.S. Department of Energy, 1980). Production from this district has exceeded 77,000 tons (69,500 metric tons) of U_3O_8 (Holen and Fitch, 1982). One of these deposits, Gulf's Mt. Taylor, contains more than 100 million pounds (45,000 metric tons) of U_3O_8 (Cheney, 1981; Jackson, 1977). More than 326,000 tons (296,000 metric tons) of U_3O_8 at an average grade of 0.10% U_3O_8 is estimated to occur in the Ambrosia Lake-Mt. Taylor trend (Holen and Fitch, 1982).

The Morrison Formation in this area is approximately 600-700 ft (183-213 m) thick, about the same thickness as in the Laguna subdistrict. However, the Westwater Canyon and the Recapture Members are thicker in the Ambrosia Lake area than at Laguna. The Jackpile sandstone is absent in the Ambrosia Lake area. The Westwater Canyon Member and the Poison Canyon sandstone are the principle sandstone hosts for mineralization in the Ambrosia Lake subdistrict. The Westwater Canyon Member consists of three or more thick-bedded, coarse-grained, arkosic sandstones separated by thin beds of shale and siltstone (Hilpert, 1969). The Poison Canyon sandstone is the basal sandstone of the Brushy Basin

Member and consists of arkosic sandstone similar in appearance and composition to the Westwater Canyon sandstones.

Mineralization ranges in depth from the surface at Poison Canyon to 700 to 900 feet (213-274 meters) at Ambrosia Lake, to 3,300 feet (1,060 meters) at Mt. Taylor.

Uranium mineralization occurs as primary-tabular and redistributed ore bodies. Primary-tabular ore bodies are typical of the occurrences elsewhere in the district. This mineralization is not directly controlled by faults, fractures, or folds; however, they tend to subparallel depositional features such as channel configuration, cross-stratification, and intraformational disconformities. These ore deposits occur as groups of lenses or pods and may split and occupy several stratigraphic horizons. The ore trends are well developed in the Ambrosia Lake-Mt. Taylor area (Fig. 11).

Redistributed ore bodies are geochemical cell-controlled and in places localized along fractures and faults. Multiple horizons of "stacked" ore along Laramide faults may attain a thickness of over 100 ft (30 m). These ore bodies are closely associated with primary tabular ore bodies and grade into them (Hilpert, 1969). Fracture-controlled redistributed-ore occurs in the western portion of Ambrosia Lake (Granger and others, 1961) and at Poison Canyon mine (Tessendorf, 1980). At the Poison Canyon mine, remnants of ore around fossil logs in limonitic sandstones occurs updip from fracture-controlled ore (Tessendorf, 1980).

Geochemical cell-controlled, redistributed ore is found in

the Ambrosia Lake area, but may be difficult to distinguish from primary tabular ore. Alteration patterns suggest redistribution and remobilization of primary tabular ore at the Sandstone mine (Foster, J. F. and Quintanar, 1980). Small roll-type deposits occur at the Johnny M mine (Falkowski, 1980a, b). Relict or remnant mineralization occurs in section 28, T. 14 N., R. 10 W. (D. A. Smith, and Peterson, 1980) section 23, T. 14 N., R. 10 W. (Harlen Holen, pers. commun., 1983) and at Poison Canyon mine (Tessendorf, 1980).

The Johnny M mine is one of several deposits in the Grants uranium district where ore occurs in both the Poison Canyon sandstone and the Westwater Canyon Member (Falkowski, 1980a, b). Primary-tabular and roll-type ore occur in the Westwater Canyon Member where organic debris is abundant. Uranium mineralization commonly occurs around fossil logs and debris accumulations and shows the direction of the groundwater flow (Falkowski, 1980a, b). Mineralization in the overlying Poison Canyon sandstone is more massive and lower in grade than ore in the Westwater Canyon Member. Organic debris and fossil logs are not common in the Poison Canyon sandstone, and no roll-type deposits have been delineated.

The most recent exploration activity in the Ambrosia Lake subdistrict is at La Jara Mesa (12N.9W.12.300, Appendix 1) where Midas has discovered a small- to medium-sized ore body in the Poison Canyon sandstone at about 600 ft (183 m) depth. This ore body is probably an extension of the Taffy mine (12N.9W.11.334, Appendix 1). Homestake is studying the feasibility of mining this ore body. Recent reports indicate there is a potential for 10

million lbs (4.5 million kg) of uranium on the property (New Mexico Uranium Newsletter, August 1983).

Uranium occurrences are found in the basal Recapture Member (Appendix 1); however, none of these deposits have yielded any ore. The extent of these occurrences is not known, although Kerndamex found good, high-grade ore northwest of San Mateo (Harlen Holen, pers. commun., 1983). Small to medium ore deposits are found in the Todilto Limestone, as previously discussed. Although, exact quantities of reserves in the Morrison Formation and Todilto Limestone in this subdistrict are not available due to proprietary information, they are substantial and mining will continue, providing economic conditions improve. The majority of the potential uranium resources are estimated to occur in the Westwater Canyon Member, but potential resources are also thought to occur in the Recapture Member, the Todilto Limestone, and Cretaceous Dakota Sandstone (U.S. Department of Energy, 1980).

Smith Lake subdistrict

The Smith Lake subdistrict is southwest of Crownpoint and north of Thoreau in McKinley County (Fig. 4). Eight mines in this area have produced ore in the past; they are Mariano Lake, Black Jack No. 2, Mac No. 2, Ruby No. 1, 2, and 3, and Black Jack No. 1 (Fig. 13). Two additional ore bodies occur in the area, Phillip's section 20 and Western Nuclear's Ruby No. 4 (Fig. 13). Development of the Ruby No. 4 ore body has begun and production will start upon reopening of the Ruby No. 3 decline.

Only one mine, the Black Jack No. 1, and several mineralized

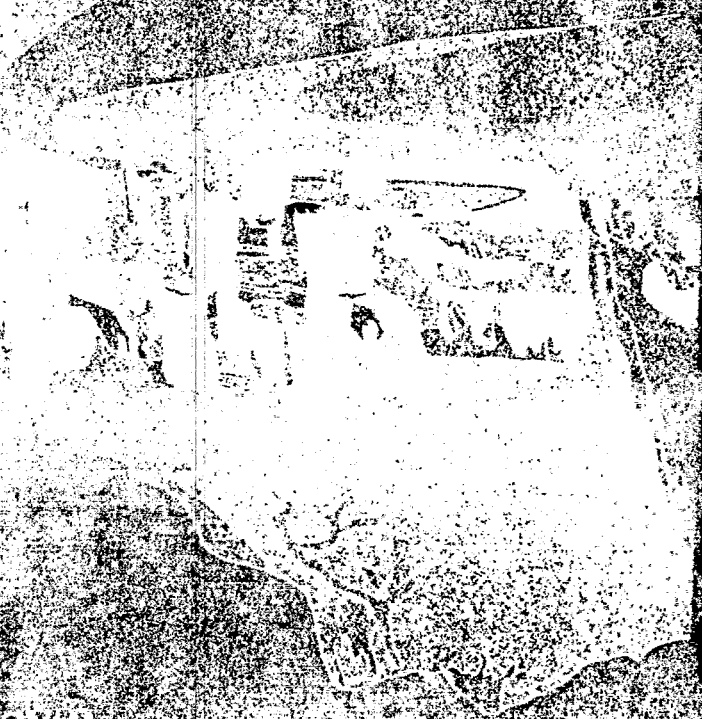
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ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

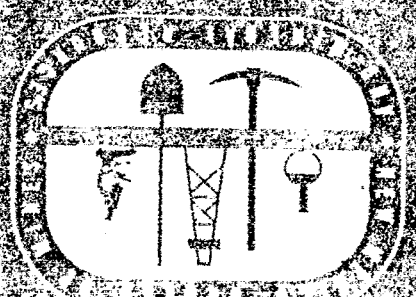
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Appendix 3 - Uranium production of individual mines in New Mexico

Uranium production from ore deposits in New Mexico was compiled by the U.S. Atomic Energy Commission (AEC) and succeeding agencies the U.S. Energy Research and Development Administration (ERDA) and the U.S. Department of Energy (DOE). Production statistics for individual mines that operated from 1948 to 1970 have been released and are tabulated in Table 3-1. These are the best records available. Production statistics for individual mines that operated from 1971 to present are confidential; however, these producing mines have been grouped into production classes in Table 3-2.

The occurrence number refers to the number, based on its location, given in appendix 1. The type of deposit refers to the NURE classification as modified for this report (see Introduction). The Host Rock symbols are defined as follows: pE-Precambrian, C-Cambrian sediments, Pm-Pennsylvanian Madera Limestone, Pma-Magdalena Group, Ps-Permian Sangre de Cristo Formation, Pa-Abo Formation, Pc-Cutler Formation, Psa-San Andres Limestone, TC -Triassic Chinle Formation, Jt-Jurassic Todilto Limestone, Je-Entrada Sandstone, Jm-Morrison Formation, Jmsw-Salt Wash Member, Jmr-Recapture Member, Jmw-Westwater Canyon Member, Jmp-Poison Canyon sandstone, Jmb-Brushy Basin Member, Jmbj-Jackpile sandstone, Kd-Cretaceous Dakota Sandstone, Ku-U-bar Formation, Kp-Point Lookout Sandstone, Kc-Crevasse Canyon Formation, Tb-Tertiary Baca Formation, To-Ojo Alamo Sandstone, Tp-Popotosa Formation, Ts-Santa Fe Group, Te-Espinosa Formation, Tv-Tertiary volcanic rocks, and Ti-Tertiary intrusive rocks.

Number	Mine Name	Tons Ore	Pounds U ₃ O ₈	%U ₃ O ₈	Pounds V ₂ O ₅	%V ₂ O ₅	Type of Deposit	Host Rock	Periods of Production/ Shipper
13N.9W.20.321	Mesa Top Mine	100,261	512,965	0.24	144,610	—	sandstone	Jmp	1954-1957 - Lea Exploration; 1957-Holly Minerals and Lea
13N.10W.4.244	Pat - Section 4 (Dakota Mine)	5,069	12,645	0.12	2,478	—	sandstone	Jmw, Kd	1952-1959 - Dakota Mining Co.; 1962-1963-Farris Mines, Inc.
13N.9W.19.420	¹ Poison Canyon	217,066	1,004,574	0.23	338,094	—	sandstone	Jmp	1952-1959 - Haystack Mountain Development Corp.; 1960- 1962-Farris Mines Inc.
14N.11W.20.113	Red Cap Group (T Group)	195	497	0.13	951	0.24	limestone	Jt	1952-1953 - Navajo Develop- ment Co.; 1953-Fitzhugh & Doerrie
13N.10W.16.134	Red Point Lode	402	1,223	0.13	746	0.07	limestone	Jt	1952-1955 - R.M. Shaw
14N.11W.20.144	Red Top Mines	165	390	0.12	1,207	0.39	limestone	Jt	1955 - Red Top Uranium Mining Co.
14N.9W.34.424	¹ Sandstone	1,034,255	3,540,829	0.17	—	—	sandstone	Jmw	1959-1963 - Phillips Petroleum Co.; 1963-1970- United Nuclear Corp.
13N.9W.1.200	¹ Section 1 (13N-9W) mined through Cliffside	148,066	1,699,137	0.57	—	—	sandstone	Jmw	1967 - Kerr-McGee; 1969-1970- Kerr-McGee and Nation Lead
15N.16W.3.332	Section 3 (15N-16W) Santa Fe-Christensen Rate Nest Mine	324	1,836	0.28	404	—	sandstone (coal)	Kd	1957 - Christensen and Ram Uranium Co.; 1957-1958-Ram Uranium Co.
13N.10W.5.144	Section 5 (13N-10W)	23	54	0.12	—	—	sandstone	Kd	1958 - Westvaco
13N.9W.8.114	Section 8 (13N-9W) Spencer Shaft	47,808	165,319	0.17	—	—	sandstone	Jmp	1958-1960 - United Western; 1961-Hyde and Casper; 1964- 1966-W.D. Trippi; 1966-1967- James J. Goode
14N.10W.10.244	¹ Section 10 (14N-10W)	130,767	510,935	0.20	—	—	sandstone	Jmw	1957-1962 - Karmac Nuclear; 1964-Homestake-Sapin
14N.10W.12.411	¹ Section 12 (14N-10W)	74,975	211,073	0.14	—	—	sandstone	Jmw	1961 - Anderson Development Corp.; 1962-1963-Stella Dysart
14N.10W.15.441	¹ Section 15 (14N-10W)	1,213,814	3,625,924	0.15	—	—	sandstone	Jmw	1958-1961 - Homestake-Sapin; 1961-1965-Rio and Home- stake-Sapin; 1966-1969- Homestake-Sapin; 1969-1970- United Nuclear-Homestake
14N.9W.17.323	¹ Section 17 (14N-9W)	544,164	2,315,182	0.21	—	—	sandstone	Jmw	1960-1964 - Karmac Nuclear Corp.; 1965-1970-Kerr-McGee
13N.10W.18.341	Section 18 (13N-10W) (Indian Allotment)	25,796	90,175	0.19	75,342	0.30	limestone	Jt	1952 - Sutton, Thompson, Williams; 1953-Williams; 1955-Santa Fe Uranium; 1955- 1956-Santa Fe Uranium and Federal Uranium; 1957-1959- Federal Uranium; 1963-1964- Mesa Mining Co.; 1966-Cibola Mining Co.
14N.9W.18.400	¹ Section 18 (14N-9W) mined through Sec. 17	501,946	1,506,447	0.16	—	—	sandstone	Jmw	1962-1964 - Karmac Nuclear; 1965-1970-Kerr-McGee
14N.9W.20.114	¹ Section 20 (14N.9W) mined through Sec. 17	486,375	2,223,977	0.23	—	—	sandstone	Jmw	1962 - Kerr-McGee
14N.10W.22.223	¹ Section 22 (14N-10W) heap leach	2,189,051	11,605,672	0.18	—	—	sandstone	Jmw	1958-1964 - Karmac Nuclear; 1965-1970-Kerr-McGee
14N.10W.23.134	¹ Section 23 (14N-10W)	2,528,797	9,679,773	0.19	—	—	sandstone	Jmw	1959-1968 - Homestake-Sapin; 1969-1970-Homestake-United Nuclear
13N.10W.23.444	Section 23 (13N-10W)	21,826	138,541	0.32	10,256	0.06	limestone	Jt	1957-1965 - Haystack Mountain Development Corp.; 1965- 1966-Santa Fe Pacific
13N.9W.24.121	Section 24 (13N-9W) Chill Wills, Rialto (Section 13)	10,950	37,693	0.17	—	—	sandstone	Jmp	1960-1963 - Febco Mines, Inc.
13N.11W.24.222	Section 24 (13N-11W) Indian Allotment to Nana-A-Bah Vandever	24,638	115,075	0.22	85,545	0.18	limestone	Jt	1952-1954 - Glen Williams; 1955-1956-Santa Fe Uranium; 1955-Federal Uranium Corp. Santa Fe Uranium; 1956-1957- Federal Uranium Corp.
14N.10W.24.332	¹ Section 24 (14N-10W) Heap leach	1,904,502	7,071,564	0.19	—	—	sandstone	Jmw	1959-1964 - Kerr-McGee Nuclear; 1965-1970-Kerr- McGee
13N.10W.25.411	¹ Section 25 (13N-10W)	235,156	950,058	0.20	153,657	0.12	limestone	Jt	1952 - A T and SF RR; 1955- 1961-Haystack Mountain De- velopment Corp.; 1962-1963- Santa Fe Pacific; 1963- Farris Mines, Inc.; 1963- 1965-Santa Fe Pacific; 1965- 1966-Farris Mines, Inc.; 1968-Homestake; 1969-1970- United Nuclear Corp.
14N.10W.25.144	¹ Section 25 (14N-10W)	1,791,048	6,444,009	0.18	—	—	sandstone	Jmw	1959-1969 - Homestake-Sapin; 1969-1970-Homestake-United Nuclear
13N.10W.26.221	¹ Section 26 (13N-10W) Desidero Group	11,110	83,752	0.30	17,518	0.00	limestone	Jt	1952-1957 - Harosh Mines
14N.10W.26.220	¹ Section 26 (14N-10W) mined through Section 24	362,110	1,190,696	0.17	—	—	sandstone	Jmw	1965-1970 - Kerr-McGee

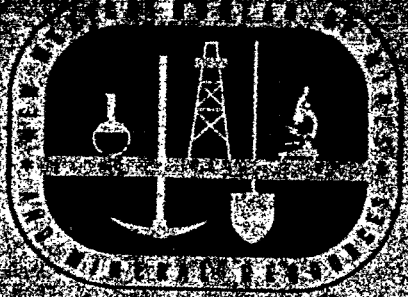
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NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

Uranium and Thorium

Geological Survey of New Mexico
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included; for some occurrences this information is company confidential or very extensive. For other occurrences, very little information could be obtained. Each description consists of sixteen entries or less (depending upon available information) keyed by number and contains the information described below.

1: Occurrence number or map number refers to the location or approximate location of each occurrence, prospect, deposit or mine. The numbering system used is based upon the township, range, and section land-grid system (fig. 1-3) and is used by the New Mexico State Engineer for numbering water wells and springs. In this system, each occurrence has a unique location number consisting of four parts separated by periods (i.e. 5N.10W.24.213). The first part refers to the township, the second part to the range, and the third part to the section. The fourth part locates the occurrence to the nearest quarter-quarter-section block as indicated in figure 1-3. An occurrence designated 5N.10W.24.213 is located in the SW1/4, NW1/4, NE1/4 of section 24, T. 5 N., R. 10 W. Some occurrences are only located to the nearest section, quarter-section, or quarter-quarter section because the occurrence cannot be more accurately located or the occurrence extends over the entire given area. In unsurveyed areas, the locations are approximated by projecting section lines.

2: The name of the occurrence, prospect, deposit, or mine as found in the literature is given. Aliases are given in parenthesis. Earlier reports have misidentified some of

these properties; these incorrect names are listed as aliases. Unnamed or unknown properties have no other identification.

- 3: The location of the occurrence, prospect, deposit, or mine is given by the section, township, and range (land-grid system) and by latitude and longitude. Areas not surveyed according to the land-grid system are indicated by the word "unsurveyed"; section lines are then projected. If there is any uncertainty with respect to the location, the latitude and longitude is approximated or is omitted entirely and the word "approximate" may be used. The locations are verified from the literature and those examined by the author and by Orin J. Anderson are exact.
- 4: The name of the 7-1/2- or 15-minute topographical quadrangle map on which the occurrence is located and the elevation are given.
- 5: Mining district (as defined by File and Northrop, 1966) or geographical area is given.
- 6: Commodities present at the locality (including U-uranium, Th-thorium, V-vanadium, Cu-copper, Mo-molybdenum, Se-selenium, Pb-lead, Zn-zinc, Ag-silver, Au-gold, REE-rare-earth elements, Mn-manganese, Ti-titanium, Nb-niobium, Ta-tantalum, Ni-nickel).
- 7: The extent of development or prospecting is briefly described.
- 8: Production figures for uranium and vanadium are from the

U.S. Atomic Energy Commission, government contracts only, for the years 1948 through 1970 (appendix 3). These are the best records available. Other production information is obtained from cited sources.

- 9: Radioactivity measurements at the locality are given as counts per second (cps). A Geometrics Gamma Ray scintillometer, model GR-101A was used by the author and Orin J. Anderson (Anderson, O.J., 1980). Background (bkgd) radioactivity and high or average radioactivity are given. Occasionally, other radiometric readings are given as times background radioactivity as obtained from cited sources.
- 10: The formation name and geologic age of the host rock is given.
- 11: Briefly describes the geology, host rock, and character of the occurrence.
- 12: Lists important radioactive minerals and chemical analyses. Samples collected by the author are listed as NMBMMR chem lab or NMBMMR XRF lab, date assayed, and sample number; and are listed collectively in appendix 2.
- 13: Refers to a modified classification used by the U.S. Department of Energy (table 2) as described in the introduction of this report.
- 14: Comments or additional information is given. Any published mine maps or geologic cross-sections of the locality will be cited.
- 15: References or sources of information are listed in an abbreviated form and arranged in chronologic order. If

the occurrence was examined by the author, it is indicated by FN (field notes) and the date of reconnaissance. Published reports are given as last name of author(s) and year of publication in parenthesis; the complete citation may be found in the bibliography (appendix 4). Occasionally, the year of publication is followed by a page number (i.e. 1956, p. 32) or by a number (i.e. 1956, #56) which refers to the page number or property number used in that publication. Some of the cited references may not mention or describe the occurrence specifically; however, it is included because it describes the geology of the locality or includes a geologic map of the area. The U.S. Atomic Energy Commission Preliminary Reconnaissance Reports (PRR) are cited by report number, prefixed with PRR, and by year in parenthesis or as U.S. Atomic Energy Commission (1970). The PRR's are tabulated separately in appendix 5. Unpublished reports and files are cited last and are not cited in the bibliography. The most recent date of information is given in parenthesis. Many of these unpublished sources are abbreviated as follows: NMBMMR files (New Mexico Bureau of Mines and Mineral Resources - Virginia McLemore and Robert W. Eveleth files), USAEC files (U.S. Atomic Energy Commission in Grand Junction, Colorado), USDOE files (U.S. Department of Energy in Grand Junction, Colorado), USBM (U.S. Bureau of Mines), CRIB (Computerized Resource Information Bank, U.S.

Geological Survey), MILS (Mineral Industry Location Survey, U.S. Bureau of Mines), PC (personal communication), and WC (written communication). Copies of most of these reports are available for inspection at the New Mexico Bureau of Mines and Mineral Resources offices.

- 16: Indicates which figures included in this report concerns the occurrence.

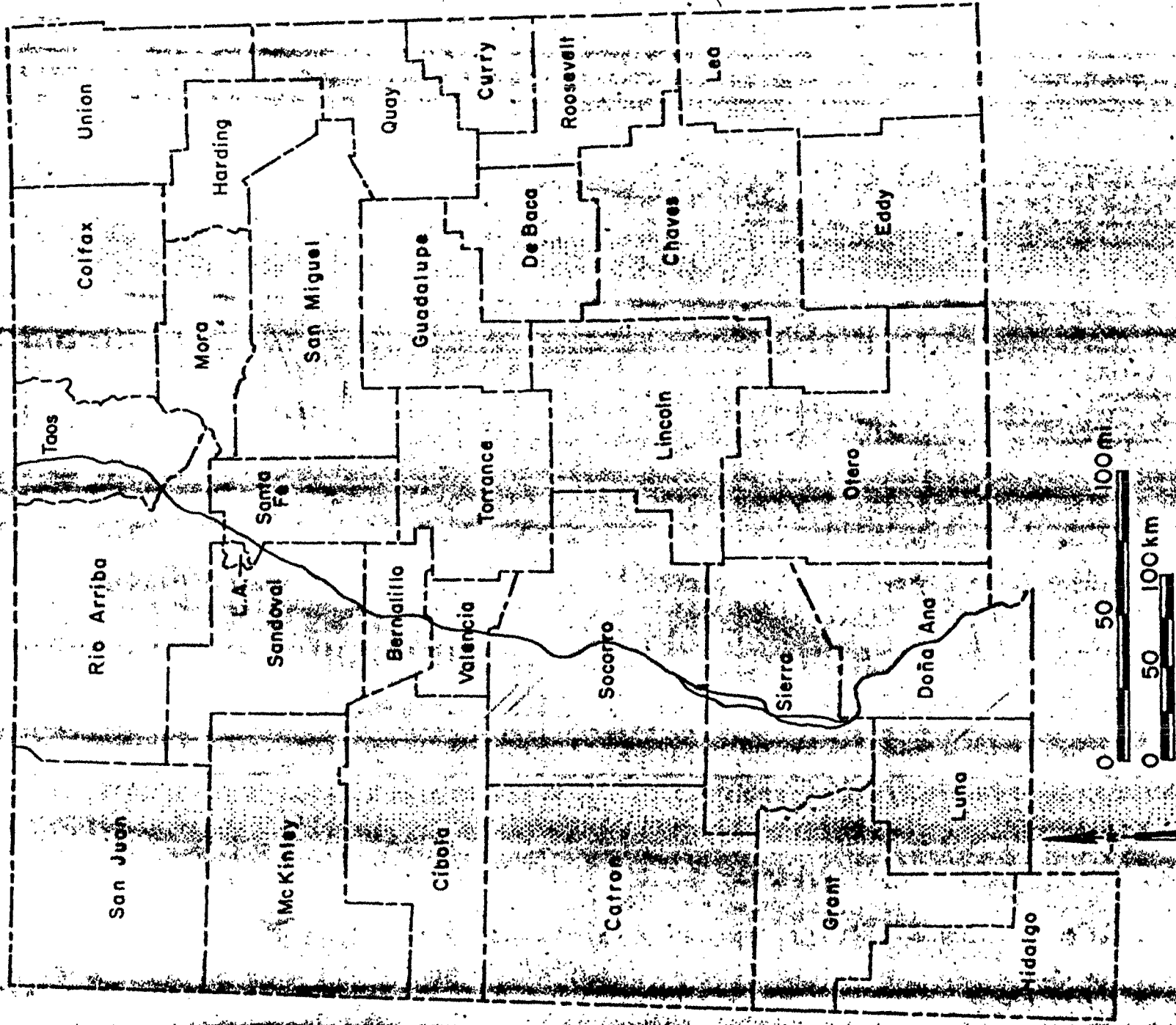
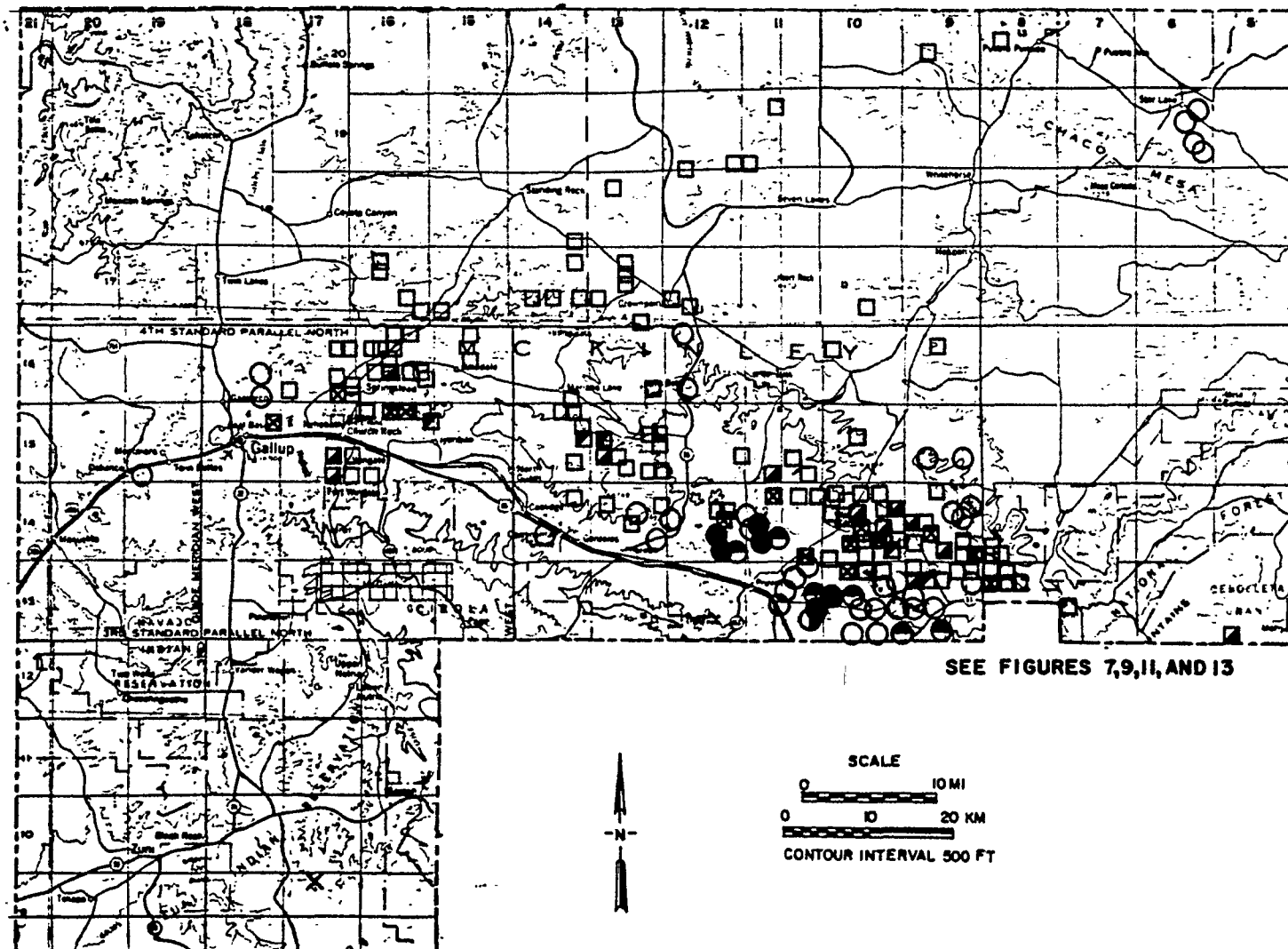


Figure 1-1 - Counties in New Mexico

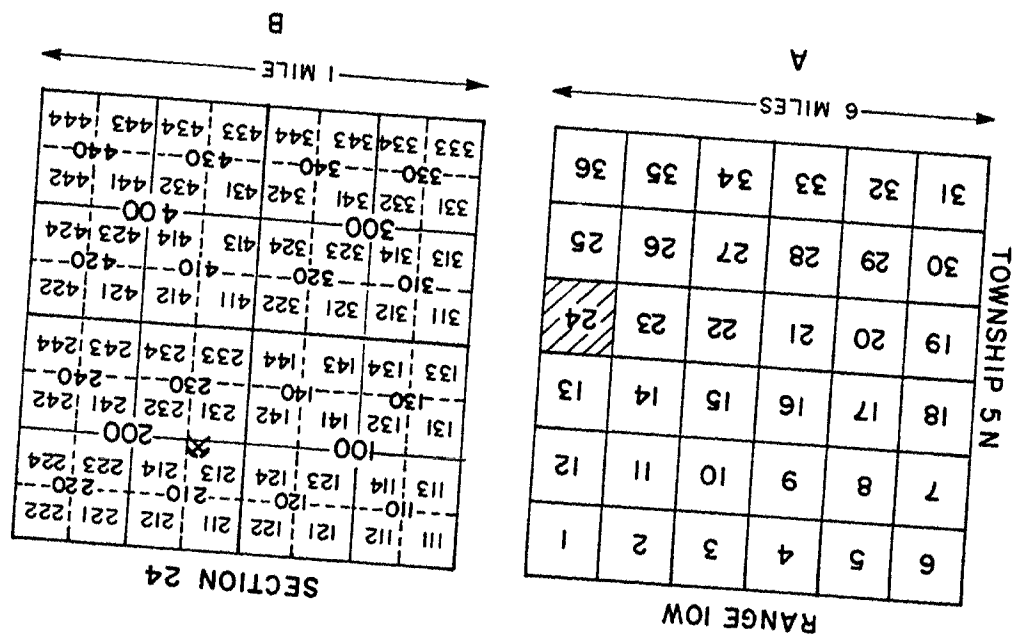
FIGURE 1-19-RADIOACTIVE OCCURRENCES IN MCKINLEY COUNTY, NEW MEXICO



SEE FIGURES 7,9,11, AND 13

Figure 1-3—Method of numbering uranium and thorium occurrences.

A) Subdivision of a township into sections,
 B) Subdivision of a section into quarter-quarter-section blocks. Mine symbol indicates location
 of an occurrence numbered 5N.10W.24.213.



- 1: 13N.11W.24.222
2: Section 24 (Indian Allotment, Nan-A-Bah, Glen and Edith)
3: NE1/4 24 T13N R11W
4: Bluewater 7-1/2 Elevation 7,110 ft
5: Ambrosia Lake subdistrict-Grants uranium district
6: U
7: open pit (15-20 ft deep)
8: 24,638 tons ore yielding 115,075 lbs U₃O₈ (0.22%); 85,545 lbs V₂O₅
10: Jurassic Todilto Limestone
11: several orebodies, largest was 640-ft long and 100-145 ft wide, related to northwest trending folds
13: Limestone
14: mined 1952-1957
15: Green and others (1980c, #185); Anderson, O.J. (1980); Holmquist (1970, p. 106); Hilpert (1969); McLaughlin (1963); Anderson, E.C. (1955); USAEC files (1957)

- 1: 14N.10W.24.332
2: Section 24 (Section 24 and 26)
3: SW1/4 24, NE1/4 25 T14N R10W 35°25'21"N 107°51'9"W
4: Ambrosia Lake 7-1/2 Elevation 7,010 ft
5: Ambrosia Lake subdistrict-Grants uranium district
6: U, Mo
7: 848-ft vertical shaft
8: 1,904,582 tons ore yielding 7,071,564 lbs U₃O₈ (0.19%) plus 579 lbs U₃O₈ by heap leach until 1970
10: Jurassic Morrison Formation-Westwater Canyon Member
11: 4 horizons, 8-67 ft thick
13: Sandstone - primary tabular
14: mined 1959-1980 by Kerr-McGee; some ore locally in lower Brushy Basin Member; on standby status in 1982
15: FN4/5/82; Green and others (1980c, #140); Chapman, Wood, and Griswold, Inc. (1979, #30); Siemers and Austin (1979); Holmquist (1970, p. 66); Hilpert (1969, p. 40, 69, #84); Santos and Thaden (1966); U.S. Atomic Energy Commission (1959a, p. 56); USAEC files (1971); NMBMMR files (1964); CRIB (1981)

REFERENCE #28

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

Colorado School of Mines
Golden, Colorado

Richard H. De Voto

EXPLORATION

URANIUM GEOLOGY
AND EXPLORATION

BY
RICHARD H. DE VOTO

LECTURE NOTES AND REFERENCES



COLORADO SCHOOL OF MINES
GOLDEN, COLORADO 80401

MARCH, 1978

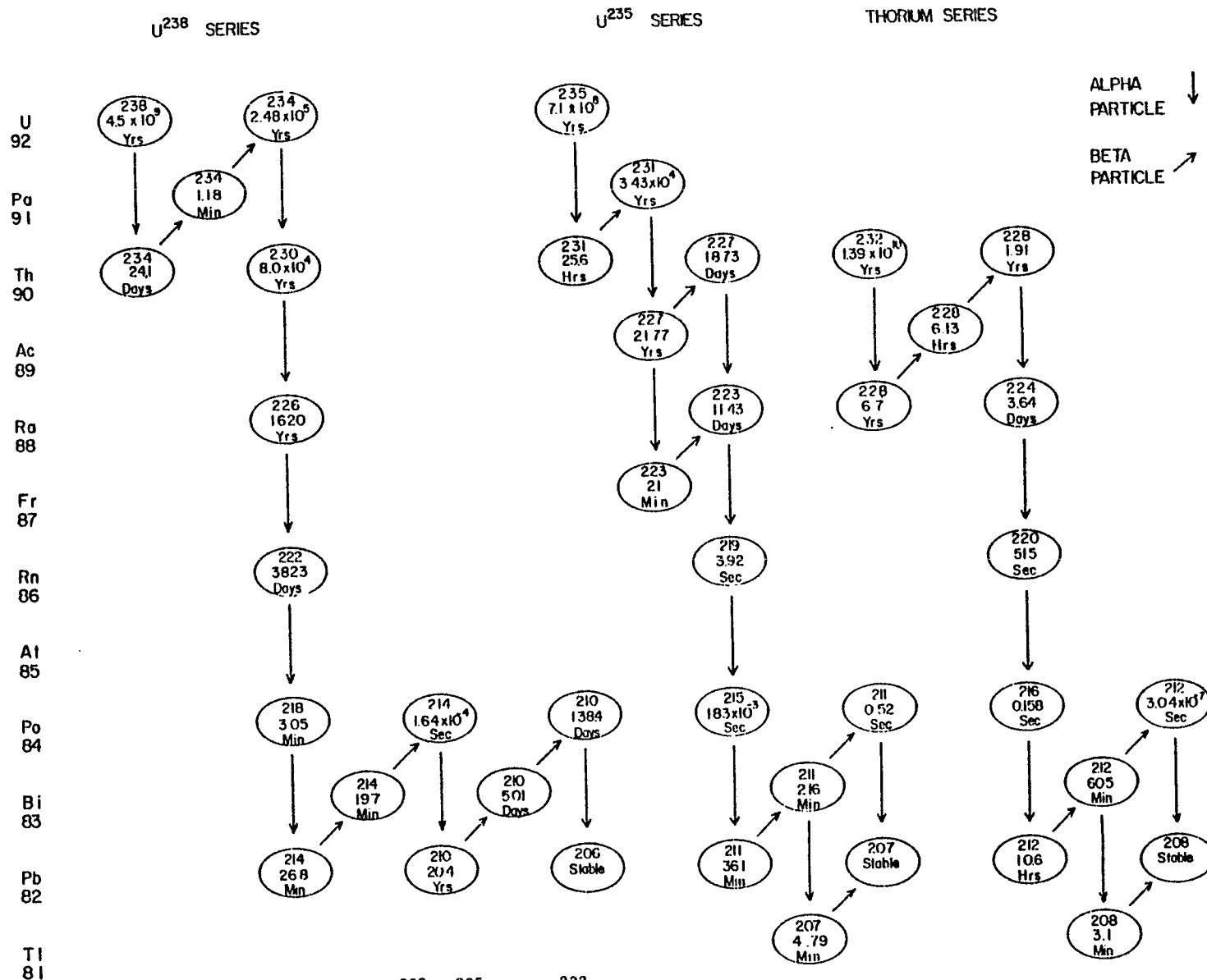


Fig. 27. U^{238} , U^{235} , and Th^{232} natural radioactivity decay series, particles emitted, and half lives. (Friedlander, Kennedy, and Miller, 1964)

F. Organic-rich limestones (epigenetic)

1. Dynamic ground water system
2. Ocean water (2ppb U) or oxidizing uraniferous ground water by evaporitic pumping (Fig. 139)
3. Todilto U deposits, Grants, New Mexico
 - a. Algal stromatolites, organic rich
 - b. Rest on red, hematitic Entrada Sandstone
 - c. U probably derived from Fe-Mg silicates in Entrada
 - d. Evaporitic pumping of uraniferous ground water to organic-rich reducing environment in Todilto

G. Coals (epigenetic)

1. Uranium accumulation principally in low-rank coals
2. Beneath unconformity with overlying tuffaceous oxidized rocks
3. Black Hills example (Fig. 140)

H. Sulfide-bearing veins (epigenetic)

1. Beneath an unconformity (Fig. 141), or
2. at the ground surface

I. Reducing gas moving to uraniferous oxidizing water

1. H_2S , methane, or other volatile hydrocarbons move upward, through ground water
 - a. U and pyrite precipitation at ground water table (Fig. 31r)
 - b. U and pyrite precipitation at positions of maximum reduction, at or near point of introduction of reductant into oxidizing ground waters (Fig. 142):
 1. along faults (S. Texas, NW Colorado)
 2. above subcrop positions of petroliferous aquifers

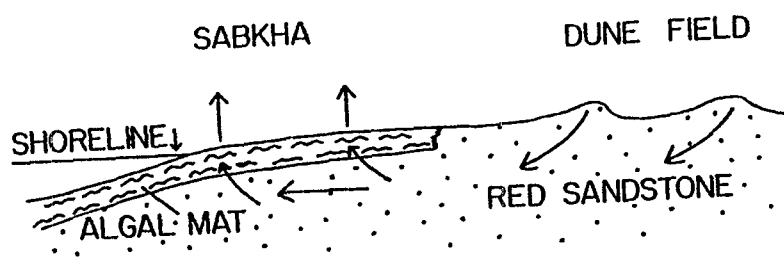


Fig. 139 Evaporitic pumping bringing oxidizing uraniferous ground water through underlying sandstone (Entrada) into reducing environment of algal stromatolitic limestones (Todilto Limestone).

REFERENCE #29

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

EPA-440/4-79-029a
December 1979

WATER-RELATED ENVIRONMENTAL FATE OF
129 PRIORITY POLLUTANTS

Volume I:

Introduction and Technical Background, Metals and Inorganics,
Pesticides and PCBs

by

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EPA Contract No. 68-01-3852
EPA Contract No. 68-01-3867

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6. ARSENIC

6.1 Statement of Probable Fate

The fate of arsenic in the aquatic environment depends largely on prevailing pH and Eh conditions. Arsenic is extremely mobile in the aquatic environment and cycles through the water column, sediments and biota. Although the equilibrium chemistry of arsenic has been extensively discussed in the literature, no information regarding the kinetics of arsenic reactions in the environment was found. It appears that, in most cases, the sediments and the oceans are the primary sinks for arsenic in the aquatic environment.

6.2 Identification - Geochemistry of Arsenic

Arsenic is considered to be a rare but ubiquitous element in the earth's crust. The average abundance of crustal arsenic has been established at 5 ppm (Weast 1977). Arsenic is the third member of group VB of the periodic system, which also includes nitrogen, phosphorus, antimony, and bismuth. In some of its chemical reactions, arsenic behaves much like phosphorus and antimony.

In the natural environment, four oxidation states are possible for arsenic: the -3 state, the metallic (0) state, and the +3 and +5 states. The metallic state is not uncommon for the element in certain types of mineral deposits. The +3 and +5 states are common in a variety of complex minerals and in dissolved salts in natural waters. The -3 state is present in gaseous AsH_3 (arsine) which may form under some natural conditions. Because of its multiple oxidation states and its tendency to form soluble complexes, the geochemistry of arsenic is intricate and not well characterized. The element most commonly associated with arsenic in nature is sulfur (Boyle and Jonasson 1973).

In all, there are 100 or more arsenic bearing minerals known to occur in nature. The principal arsenic minerals are arsenopyrite (FeAsS), niccolite (NiAs), cobaltite (CoAsS), tennantite ($\text{Cu}_{12}\text{As}_4\text{S}_{13}$), enargite (Cu_3AsS_4), native arsenic (As), orpiment (As_2S_3), realgar (AsS), proussite (Ag_3AsS_3), scorodite ($(\text{Fe}, \text{Al})(\text{AsO}_4) \cdot 2\text{H}_2\text{O}$), bendanite ($\text{PbFe}_3(\text{AsO}_4)(\text{SO}_4)(\text{OH})_6$), olivenite ($\text{Cu}_2\text{AsO}_4\text{OH}$), mimetite ($\text{Pb}_5(\text{PO}_4, \text{AsO}_4)_3\text{Cl}$), arsenolite (As_2O_3), erythrite ($\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$), and annabergite ($\text{Ni}_3(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$). Arsenic also occurs in minor quantities in practically all the common sulfides and in a great variety of secondary oxidation products, particularly in sulfates and phosphates (Boyle and Jonasson 1973). The generalized geochemical cycle of arsenic is shown in Figure 6-1.

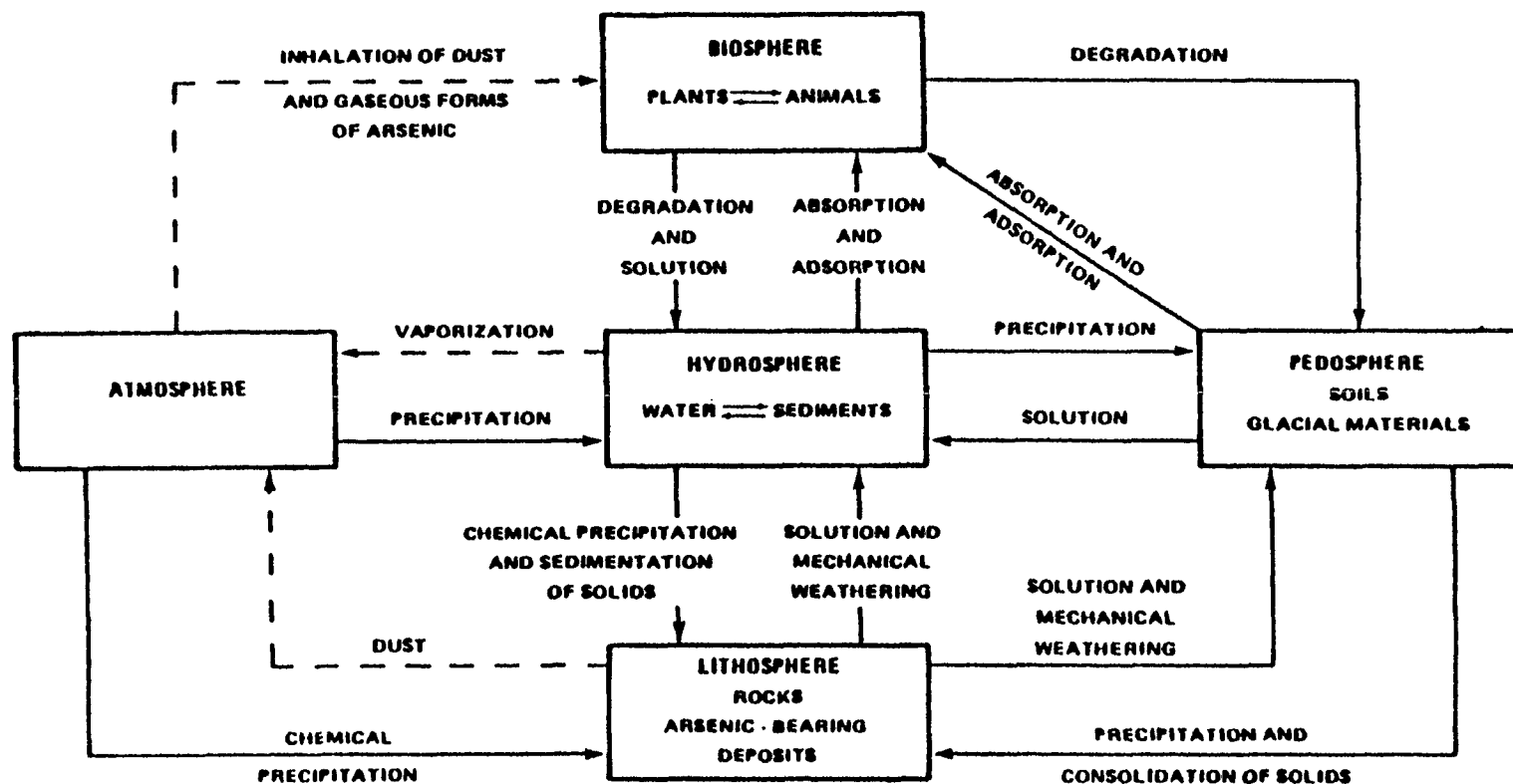


Figure 6-1 The generalized geochemical cycle of arsenic. From Boyle and Jonasson (1973).

Arsenic has no aqueous cationic chemistry other than in organic quaternary salts (Cotton and Wilkinson 1972). The oxo acids, arsenious acid (H_3AsO_3) and arsenic acid (H_3AsO_4), are the prevalent forms of arsenic in aerobic waters. Arsenic can form complexes with a number of organic compounds, most of which increase solubility. ||

The atomic number of arsenic is 33; its atomic weight is 74.91; density is 5.72 (20°C); melting point (28 atm.) is 817°C; and boiling point is 613°C (Weast 1977).

The CAS number of arsenic is 7440-38-2; the TSL number is A-1418-8227.

6.3 Summary of Fate Data

6.3.1 Photolysis

No evidence was found that photolysis is an important mechanism in determining the fate of arsenic compounds.

6.3.2 Chemical Speciation

In aquatic systems, arsenic has an unusually complex chemistry with oxidation-reduction, ligand exchange, precipitation, and adsorption reactions all taking place. Arsenic is stable in four oxidation states (+5, +3, 0, -3) under Eh conditions occurring in aquatic systems. Arsenic metal occurs only rarely and the -3 oxidation state is stable only at extremely low Eh values. Since the valence state of arsenic is extremely important in determining toxicity (the +3 state is much more toxic than the +5 state; National Academy of Sciences 1976) as well as complexation behavior, the chemical speciation of arsenic is very important when considering its aquatic fate. ||

Wagemann (1978) examined the typical concentrations of major and minor ionic constituents in freshwater systems in an attempt to find the possible controls on total dissolved arsenic in freshwater. He selected four metals (Ba, Cr, Fe, Ca) as possible controlling factors and studied their metal arsenates more closely in the laboratory. Barium ion, at typical freshwater concentrations, was the most likely freshwater constituent that would be capable of holding total dissolved arsenic to rather low concentrations. Based on these studies, an Eh-pH diagram (Figure 6-2), which summarizes theoretical arsenic speciation in freshwater environments, was developed.

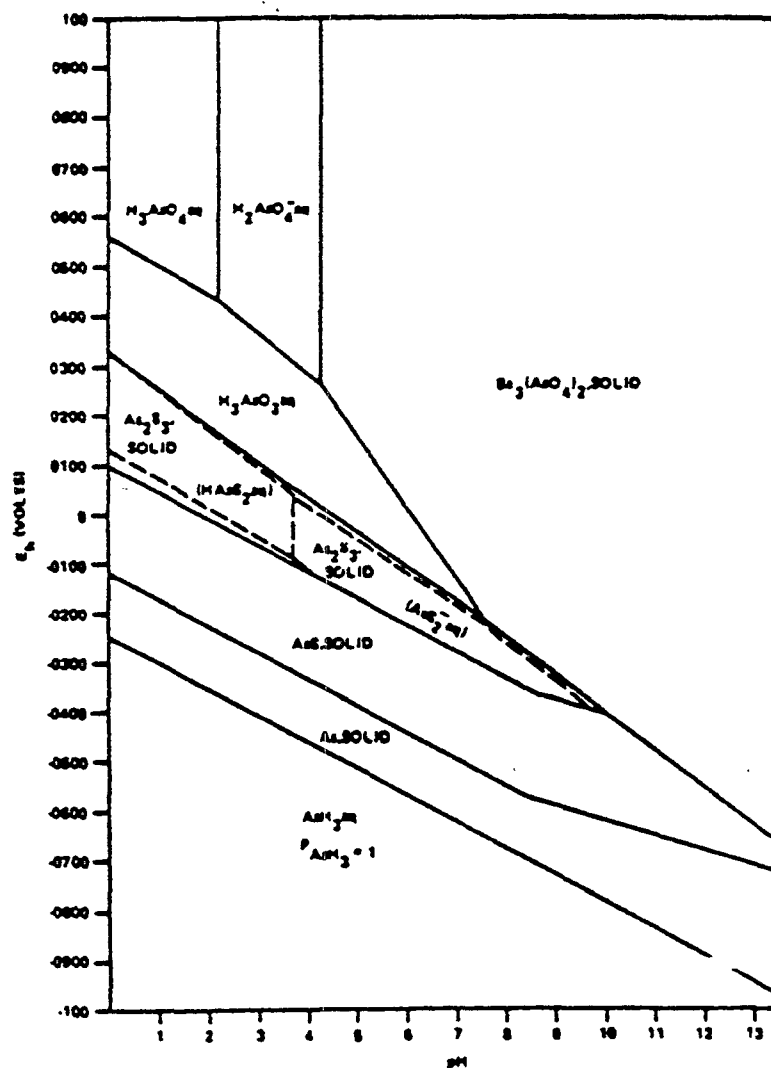


Figure 6-2 Eh-pH diagram for arsenic at 25°C and 1 atm. pressure, showing the fields of stability for the most important arsenic species in the presence of $10^{-5}M$ of total arsenic, $10^{-3}M$ of total sulfur and $2.2 \times 10^{-7}M$ of total barium. Dashed lines define domains for species enclosed in parentheses. From Wagemann (1978).

Andrese (1978) analyzed seawater from the Southern California coast and terrestrial waters from several locations in the United States for four arsenic species: arsenite, arsenate, monomethylarsonic acid, and dimethylarsinic acid. Generally, arsenate was dominant, but in waters of the photic zone, the other species were found in significant concentrations. A positive correlation was evident between the concentrations of arsenite and methylated arsenicals and biological activity. These results indicate that the speciation of arsenic in natural waters is significantly influenced by the biota. In the waters below the euphotic zone, arsenate concentrations increased with depth, suggesting regeneration from biological material. Inasmuch as arsenate is the thermodynamically stable form of arsenic under the conditions prevalent in most natural waters, the non-equilibrium species reflect the biological activity in natural waters.

These results were confirmed by the work of Waslenchuk and Windom (1978) in estuaries and Waslenchuk (1979) in rivers. Waslenchuk and Windom (1978) found that in estuaries the only detectable species was arsenate which remained in solution as fresh and salt water mixed. Complexes occurred between arsenic and low molecular weight dissolved organic matter. These complexes presumably prevented adsorptive and coprecipitative interactions with the sediments and allowed the arsenic to travel to the ocean in a dissolved form. Arsenic which enters the estuary associated with particulates, however, apparently remained so and accumulated in the sediments.

Waslenchuk (1979) found that the levels of dissolved arsenic in rivers in the southeast of the United States are controlled by the availability of arsenic, by rainwater dilution, by the extent of complexation with dissolved organic matter, and perhaps by the metabolic activity of aquatic plants. Arsenic complexation by dissolved organic matter prevents adsorptive interactions between the arsenic and solid-phase organic and inorganic materials. Despite high arsenate solubility, arsenate concentration is limited to levels below saturation, due to reactions which remove the free arsenate ion from solution. The particulate arsenic load may be as important as the dissolved load with respect to material transport in rivers. Only the dissolved load, however, is delivered to the ocean. It appears further that those biologically mediated reactions which result in arsenic species disequilibria, in the ocean and lakes, have an insignificant effect on arsenic speciation in rivers.

6.3.3 Volatilization

Volatilization of arsenic may be a significant process in extremely reducing environments where arsine (AsH_3) is formed, but under normal circumstances, it is not an important mechanism in determining the fate of arsenic after the element's introduction to the aqueous environment.

Arsine is probably oxidized rapidly in aerobic waters or the atmosphere (Parris and Brinkman 1975, 1976).

Methylated arsine derivatives may have more potential for volatilization. Trimethylarsine is quite volatile at room temperature (vapor pressure 322 torr) and is oxidized to more soluble products very slowly. Parris and Brinkman (1976) reported a rate constant of less than $10^{-2} \text{M}^{-1} \text{s}^{-1}$ for oxidation of $(\text{CH}_3)_3\text{As}$ by dissolved oxygen. In the gas phase, the rate constant for oxidation by oxygen was $10^{-6} \text{M}^{-1} \text{s}^{-1}$. Thus, trimethylarsine can travel considerable distances without undergoing chemical change, even in aerobic systems.

6.3.4 Sorption

✓ Cycling of arsenic in the aquatic environment is dominated by adsorption and desorption to sediments. Arsenic may be sorbed onto clays, ✓ aluminum hydroxide, iron oxides, and organic material (Ferguson and Gavis 1972; Jackson *et al.* 1978). In areas where phosphate minerals occur, arsenate may isomorphously substitute for phosphate (Hem 1970). Under most + conditions, coprecipitation or sorption of arsenic with hydrous oxides of iron is probably the prevalent process in the removal of dissolved arsenic. The oxyanions of both arsenic and arsenous acid can coprecipitate with hydrous iron and manganese oxides (Ferguson and Gavis 1972).

Gupta and Chen (1978) studied the adsorption of As(III) and As(V) onto alumina, bauxite, and carbon under various pH and salinity conditions in the laboratory. The results indicate that: (1) the rate of adsorption and the extent of arsenic removal decrease with increasing salinity; (2) pentavalent arsenic species have a greater adsorptive affinity for the materials tested than do trivalent species; (3) alumina and bauxite are much more effective adsorbents than carbon; and (4) adsorption decreases with increasing pH above pH 9 for As(III) and above pH 7 for As(V). These data show that adsorption will be most important in aerobic, acidic, fresh { waters. As conditions become more reducing, alkaline, and/or saline, arsenic is less likely to be adsorbed and more likely to remain dissolved.

At Tacoma, Washington, a smelter discharges large amounts of As_2O_5 into the air and Puget Sound. Sediments near the smelter contain high levels of arsenic (up to 10,000 ppm). Surface seawater samples taken next to the smelter contained a maximum 1200 ppb arsenic. The concentration decreased very rapidly with distance to about 4 ppb within one mile. Crecelius *et al.* (1975) explained this phenomenon by the rapid absorption of arsenic into the sediments of Puget Sound. Crecelius (1975) estimated that for Lake Washington, which received high loadings of arsenic, approxi-

mately 55% of the arsenic entering the lake was removed to the sediments. About 60% of the arsenic in the sediments was extractable with the iron-manganese compounds, indicating that sorption or coprecipitation was the primary removal process. Of the riverine input to the lake, 65% of the arsenic was dissolved and 35% was associated with particles. Since much of the arsenic entering the lake originated from the nearby smelter and was probably chemically bound to particles which subsequently settled to the sediments, it is quite possible that in uncontaminated environments, less arsenic would be removed to the sediments and a greater proportion of the arsenic in the sediments would be associated with the extractable iron-manganese compounds.

La Peintre (1954) demonstrated that arsenate species are coprecipitated or adsorb onto hydrous iron oxide. Shnyukov (1963) observed that iron ores are always enriched with arsenic, owing to the high adsorptive capacity of the hydrous iron oxides and the fact that ferric arsenate is very insoluble. Arsenate species are adsorbed by aluminum hydroxide and by clays; however, bauxite and silicates are usually only moderately enriched in arsenic (Onishi and Sandell 1955). It appears, therefore, that adsorption of arsenic by sediments is one of the controlling mechanisms for its fate in the aquatic environment.

6.3.5 Bioaccumulation

Although arsenic is toxic, a number of studies have shown that it is bioaccumulated. Arsenic is accumulated by fish both from water and from food, but reported concentration factors for arsenic in aquatic organisms are generally quite low (Table 6-1).

Reay (1973) studied the arsenic levels in an arsenic-rich river, the Waikato (New Zealand), and related bioaccumulation of arsenic by aquatic plants to the total amount transported by the river. By estimating total production (ecological) and the amount of arsenic transported by the river, the author estimated that only 3-4% of the annual arsenic input to the river was bioaccumulated, with much of the balance being discharged to the sea and the remainder settling out with sediment at impoundments.

In a microcosm experiment, Isensee *et al.* (1973) investigated the bioaccumulation of two organic arsenicals, cacodylic acid and dimethylarsine, for a total of 32 days in a model ecosystem that contained algae, snails, daphnia, and fish. Fish exhibited the least accumulation, with a bioconcentration factor of 21 for cacodylic acid and 34 for dimethylarsine. Snails accumulated the compounds to a greater extent (the bioconcentration factor ranged from 110 to 446), and the two planktonic components concentrated arsenic the most, with bioconcentration factors ranging from 736 to

Table 6-1

Bioconcentration Factors for Arsenic

<u>Taxon</u>	<u>Bioconcentration Factor^a</u>	<u>Reference</u>
Freshwater Plants	333 6000	Chapman <u>et al.</u> 1968 Reay 1973
Freshwater Invertebrates	333	Chapman <u>et al.</u> 1968
Freshwater Fish	333	Chapman <u>et al.</u> 1968
Marine Plants	333	Chapman <u>et al.</u> 1968
Marine Invertebrates	333	Chapman <u>et al.</u> 1968
Marine Fish	333	Chapman <u>et al.</u> 1968

a. Bioconcentration factors are the ratio derived from the concentration of the element in the aquatic organism (in ppm wet weight) divided by the concentration of the element in water (in ppm).

2175. It was concluded that the arsenic compounds did not show a tendency to biomagnify (increase in concentration as trophic level increases); and after 32 days, about 30% of the original arsenic in solution was incorporated by the biota.

Sorensen (1976a) exposed green sunfish (Lepomis cyanellus) to various concentrations of arsenic (as sodium arsenate) in water and measured the accumulation. There appeared to be a relationship between exposure concentration and arsenic accumulation, but the data were not statistically correlated. In further experiments green sunfish were exposed to sodium arsenate under varying temperature and exposure intervals (Sorensen 1976b). Arsenic uptake by liver, gut and muscle increased with arsenic concentration in water and with temperature and exposure interval. Dead sunfish did not passively accumulate arsenic and no useful method was found for confirming arsenic-caused fish kills. Biological half-life for arsenic in gut and liver was about seven days.

Gilderhus (1966) observed the arsenic uptake by young and adult bluegills (Lepomis macrochirus) placed in ponds that had been treated with various concentrations of sodium arsenate as a herbicide. After sixteen weeks exposure, whole adult bluegills contained arsenic levels very similar to the concentration of arsenic remaining in the pond after that period. Immature bluegills attained arsenic concentrations nearly twice those present in adults. By the end of the experiment, 20 to 80 percent of the arsenic applied to the ponds remained in solution.

Sandhu (1977) measured arsenic content of fish and water in a pond accidentally sprayed with an arsenical herbicide. Arsenic levels in the pond reached 2.5 mg As/l; fish accumulated up to 12.4 µg As/g in muscle, representing a concentration factor of only five. Lake Michigan plankton and benthos were found to contain 6.0 and 6.6 µg As/g, respectively (Seydel 1972). Lake Superior plankton contained about 30 percent less. The arsenic concentrations present in phytoplankton and zooplankton were similar.

In general, fat contains more arsenic than other tissue fractions. Fish muscle tissue also accumulates arsenic; however, the biological half-life of arsenic is only seven days in green sunfish. Shellfish concentrate arsenic to a much greater extent than fish, and marine organisms contain more arsenic than freshwater species.

6.3.6 Biotransformation

Arsenic has been shown to undergo a number of biologically mediated transformations in aquatic environments, most of which involve methyl-

ation to derivatives of arsine (Johnson 1972; Wood 1975; Zingaro and Irgolic 1975). Arsenic forms stable bonds with sulfur and carbon in organic compounds, and it is the affinity of trivalent arsenic for sulfhydryl groups, most notably in amino acids, which accounts for the primary mode of arsenic toxicity (National Academy of Sciences 1976). Pentavalent arsenic is not reactive with sulfhydryl groups, but since some organisms are capable of reducing arsenate to arsenite, biological reduction in natural waters could cause an increase in the ratio of arsenite to arsenate (Braman and Foreback 1973).

In methylation studies, McBride and Wolfe (1971) demonstrated that Methanobacterium reduced and methylated arsenate under anaerobic conditions to dimethylarsine. A methyl donor, methylcobolamin in this case, was necessary. Cox and Alexander (1973) demonstrated that three species of fungi, found in sewage sludge, could produce trimethylarsine. Two of the fungi were able to form trimethylarsine from mono- or dimethylarsine, while the third was able to produce trimethylarsine from arsenite and arsenate as well. In general, more trimethylarsine was produced in acidic media than under neutral conditions. The methylarsines can be produced by a number of yeasts, bacteria, and fungi. This literature has been reviewed by Ferguson and Gavis (1972) and Woolson (1977).

The biological function of the methylation of arsenic is not known, but Braman and Foreback (1973) speculate that methylation may be a detoxification mechanism since most of the organic metabolites are considerably less toxic than arsenite. Alternatively, methylation of arsenic could be purely adventitious. In an anaerobic environment, it may be energetically preferable for organisms to transmethyrate metals rather than to synthesize methane. Only aerobic metabolism has been found to yield methylarsines and methylation may occur in the aerobic upper layer of the sediment. The probable mobility of methylarsines from the sediments to solution and to the aquatic food chain plus the increased anthropogenic discharges of arsenic could bring about ever increasing arsenic concentrations in the aquatic environment. This cyclic behavior of arsenic in biological systems has been summarized in Figure 6-3.

6.4 Data Summary

Arsenic is extremely mobile in the aquatic environment. Although a number of studies have described the equilibrium chemistry of arsenic, the rates of most of these reactions are unknown. It is evident that once in the aquatic system, arsenic cycles through several components, i.e., the water column, the sediments, the biota, and the atmosphere. Figure 6-4 summarizes this cyclical nature of arsenic.

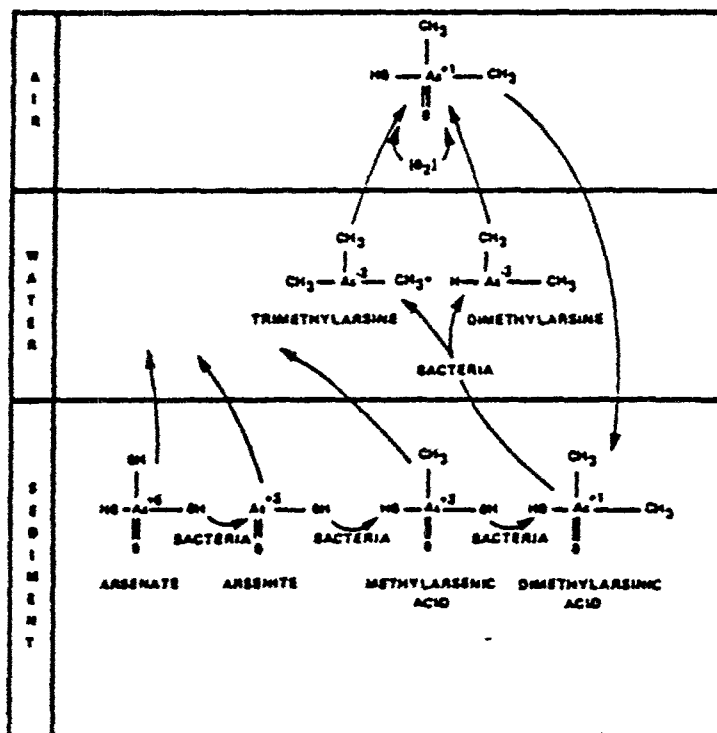


Figure 6-3 The biologic arsenic cycle in the aquatic environment.
From Wood (1975).

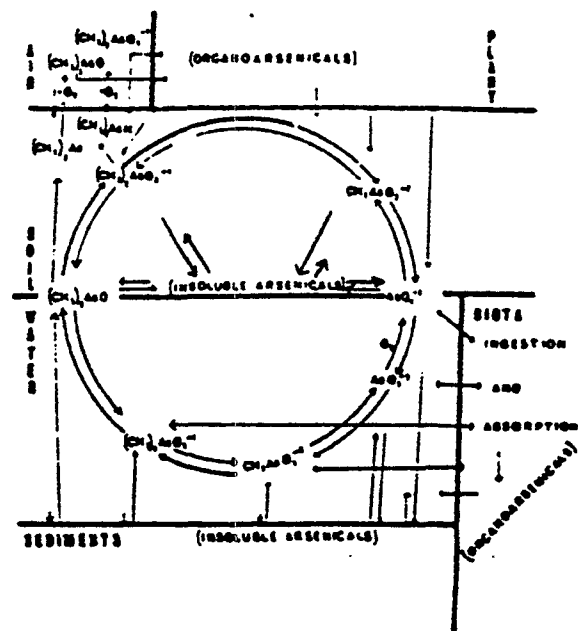


Figure 6-4 Cycle of arsenic through different environmental compartments.
From Woolson (1977).

Obviously, the fate of arsenic in the aquatic environment is a complex problem, depending on a number of factors including Eh, pH, metal sulfide and sulfide ion concentrations, presence of phosphorus minerals, iron concentration, temperature, salinity, and distribution and composition of the biota. It appears that, in most cases, the sediment is the major sink for arsenic, but that mobilization by bacteria and other benthic organisms returns much of this arsenic to the cycle. Much, if not most, of the arsenic introduced to the aquatic ecosystem is eventually transported in solution to the oceans. Table 6-2 summarizes the aquatic fate of arsenic.

Table 6-2

Summary of Aquatic Fate of Arsenic

<u>Environmental Process</u>	<u>Summary Statement</u>	<u>Confidence of Data</u>
- Photolysis	Not an important process.	Medium
Chemical Speciation ^a	Important in determining arsenic distribution and mobility. Interconversions of +3 and +5 state and organic complexation are most important.	High
Volatilization ^a	Important when biological activity or highly reducing conditions produce AsH ₃ or methylarsenics.	High
Sorption ^a	Sorption onto clays, iron oxides, and organic material are a controlling mechanism for the fate of arsenic in the aquatic environment.	High
Bioaccumulation ^a	Appears to be most significant in lower trophic levels. High toxicity lowers overall accumulation by aquatic organisms.	Medium
Biotransformation ^a	Arsenic is metabolized by a number of organisms to organic arsenicals, thereby increasing arsenic mobility in the environment.	High

a. All of the noted environmental processes are important; however, their relative importance with respect to each other is uncertain for determining final fate.

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REFERENCE # 30

NAVAJO SUPERFUND OFFICE
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JUNE '90

GROUNDWATER PROSPECTING FOR SANDSTONE-TYPE URANIUM DEPOSITS: A PRELIMINARY COMPARISON OF THE MERITS OF MINERAL-SOLUTION EQUILIBRIA, AND SINGLE-ELEMENT TRACER METHODS

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(Received May 8, 1980)

ABSTRACT

Langmuir, D. and Chatham, J.R., 1980. Groundwater prospecting for sandstone-type uranium deposits: a preliminary comparison of the merits of mineral solution equilibria, and single-element tracer methods. In: R.H. Carpenter (Editor), *Geochemical Exploration for Uranium*. *J. Geochem. Explor.*, 13: 201-219.

Groundwater quality data was collected from published sources and estimated when necessary for three sandstone-type uranium deposits in Texas and Wyoming. The purpose of the study was to compare the merits of using the computed saturation state of the groundwater with respect to uranium minerals, to that of single-element tracers in groundwater for geochemical prospecting. The uranium minerals considered were carnotite and tyuyamunite within oxidized deposits in the Catahoula Tuff in southern Texas, and uraninite and coffinite in reduced deposits within the Oakville Sandstone in southern Texas, and Wasatch Formation in northeast Wyoming. Groundwater chemical maps and profiles were constructed for the three sites, showing locations of known and probable uranium mineralization. The single tracer elements and parameters considered in the comparison were pH, Fe, SO_4 , V, U, Ra, As, Mo and Se. Mineral-saturation results were the most dependable evidence for uranium mineralization, and showed systematic trends towards saturation at distances as great as 300 m from the ore. In general, the next best indicators of ore were uranium concentrations, and vanadium concentrations in the oxidized deposit. Single tracer species As, Mo, Se and V were at or below detection in groundwaters near the reduced deposits, and except for V, provided ambiguous information in the oxidized deposit. Because of its high mobility, radium was displaced from the mineralization in the direction of groundwater flow at the Oakville Site, although its success as an ore pathfinder was equal to that of dissolved uranium at the Wasatch Site.

INTRODUCTION

The use of groundwater as a prospecting tool to locate sandstone-type uranium deposits has generally been limited to appraising the distribution of so-called pathfinder species, such as He, Ra, Rn, Mo, V, As, Se, and U in the groundwater (cf. Dyck, 1975; Dyck et al., 1976; Nichols et al., 1977; Arendt

et al., 1978; Asikainen and Kahlos, 1979; Cadigan and Felmlee, 1979; Rose and Kormer, 1979). Although these species can provide indirect evidence of an ore body, solution-mineral equilibria concepts suggest that chemical maps of such species may be inadequate. The concentration of uranium in groundwater, for example, may be lower within an ore body than in surrounding areas (DeVoto, 1978; Childers, 1979). Most uranium ore, however, contains discrete uranium minerals with which the groundwater may equilibrate. The state of saturation of the groundwater with respect to these ore minerals can provide the most direct proof of the existence of an ore body.

This paper will examine which is the better indicator of the presence, location, and size of an ore body; the saturation state of the groundwater with respect to uranium minerals, or the distribution of pathfinder or tracer elements in the groundwater. To properly consider this question, detailed information is required on the groundwater geochemistry, hydrology and geology of strata that contain known uranium ore bodies. This type of published information, when available, is found in United States government reports, including NURE (National Uranium Resources Evaluation) reports of the United States Department of Energy, and in environmental impact statements submitted by the uranium mining industry to state governments for permitting purposes. Unfortunately, details of the mineralogy, geology and hydrology are usually sparse, and specific locations of known mineralization tend to be vague. In addition, the groundwater chemical analyses may be incomplete and of poor quality, lacking data for both major and trace constituents. The absence of a field measured oxidation potential (Eh) or dissolved oxygen, and field measured pH is the most serious general deficiency in such data.

In some cases then, estimated values are needed before one can make mineral-equilibria calculations. The obvious question this raises is, in spite of the need for such estimates, are the resultant mineral saturation values accurate enough to be useful for prospecting? The above questions are addressed in this paper for sandstone-type uranium deposits in the Catahoula Tuff and Oakville Sandstone in southern Texas, and in the Wasatch Formation in northeastern Wyoming. Measured and estimated groundwater quality data from areas of these deposits have been introduced into an extensively expanded version of the computer program WATEQF (Plummer et al., 1976) which includes the thermodynamic data for uranium and vanadium minerals and solutes given by Langmuir (1977; 1978).

This same computer program was used by McNally and Langmuir (1977) to examine the status of uranium-mineral equilibria in oxidized groundwaters within Kent and Dickens Counties in northwest Texas. Using a combination of estimated data, and published groundwater chemical data from the Texas Water Development Board (Anonymous, 1972) and NURE Program (Nichols et al., 1976), they concluded that the groundwater was locally

saturated with respect to carnotite. More recently Applin and Langmuir (1978) sampled and analyzed shallow groundwaters from 68 wells (average depth 12 m) and springs in uraniferous sediments of northeast and eastern Pennsylvania. Field measurements of pH, and of Eh or dissolved oxygen were taken of most samples, along with laboratory measurements of major and minor elements, and Cl, HCO_3 , PO_4 and SO_4 . Computer calculation of the status of uranium-solution mineral equilibria showed that all the waters were undersaturated with respect to uranium minerals by at least three orders of magnitude. This result probably reflected the paucity of uranium mineralization, and the relatively high dilution of these shallow groundwaters in fractured, Paleozoic rock by groundwater recharge under climatic conditions typical of the eastern United States (average precipitation in this case about 125 cm/yr).

Using the thermodynamic data for uranium minerals and complexes given by Langmuir (1978), and estimated Eh values, Lueck (1978), Lueck et al. (1978), and Runnells et al. (1980) have shown the useful application of uranium-solution mineral equilibria concepts to the genesis of, and exploration for sandstone-type uranium and vanadium deposits of the western United States, and to their mining by in-situ leaching methods. However, no one to date has contrasted the merits of the mineral-saturation and single tracer approaches to exploration for these deposits using groundwater prospecting methods. Further, our groundwater quality data base for the western deposits is considerably larger than that evaluated by Runnells et al. (1980).

ESTIMATION OF GROUNDWATER QUALITY DATA

The use of published data to compute the status of uranium-solution mineral equilibria has required the estimation of concentrations for unmeasured species such as Ca, Mg, K, Cl, Si, and Eh. Groundwater analyses from the Catahoula Tuff in the Seguin Quadrangle (Arendt et al., 1978) lacked Si and K data. Values of 80 ppm (as SiO_2) and K = 10 ppm were assumed for these species based on average values for Catahoula groundwaters given by Weeks and Eargle (1963). Chloride was also lacking from these analyses, but because it was the major anion chloride could be estimated with good accuracy from large differences in the epm (equivalent per million) balance between cations and anions.

Nichols et al. (1977) did not measure the species Si, K, Cl, Na, Mg, Ca, and Eh in groundwaters from the Crystal City-Beeville Quadrangle immediately to the south of the area studied by Arendt et al. (1978). We estimated Na, Mg and Ca in these waters by determining the best correlation between these species and Cl, HCO_3 , specific conductance, and total epm anions using the data for the Seguin Quadrangle from Arendt et al. (Corresponding r values ranged from 0.88 to 0.98). The slope and intercept of the best-fit line were then utilized with the same independent variable to predict

data missing in the report of Nichols et al. (1977). Chloride was correlated with specific conductance (SpC) after an adjustment to remove associated large known effects of SO_4 and HCO_3 ($r = 0.98$ for the plot of Cl versus SpC). This was accomplished by dividing the conductivity by 100, which approximates the total cation or anion value in epm (Brown et al., 1970). The contributions of SO_4 and HCO_3 were removed by subtracting their known epm values from the total estimated epm value for the anions. Magnesium was strongly correlative with total anions (epm) and also with HCO_3 . Na and Ca were estimated from both the total epm of anions and from Cl. (For example, $r = 0.94$ for Na versus SpC, and $r = 0.98$ for Na versus Cl).

Estimates of concentrations of major species are usually possible with fair to good accuracy using this combination of statistical methods and epm balances. Trace species concentrations, however, were usually poorly correlated with major species concentrations, so that their estimation was rarely defensible. Estimates of Eh also must be made with considerable caution. Explanation and justification for Eh estimates is given below.

In oxidized groundwater environments the most common uranium ore minerals in sandstone-type deposits of the southwestern United States are carnotite and tyuyamunite. In reduced groundwater environments uraninite and coffinite are the usual ore minerals. The stabilities of carnotite and uraninite in terms of Eh and pH are shown in Fig. 1 for conditions fairly typical of the sandstone-type deposits. Waters that contain detectable dissolved oxygen (> 0.1 ppm) lie at the top of the carnotite field (see Lang-

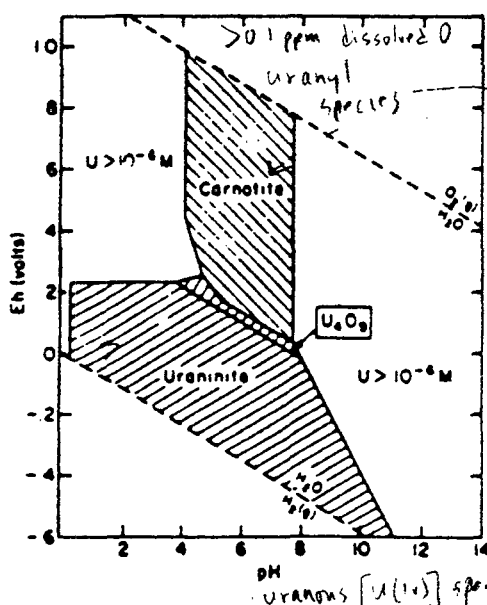
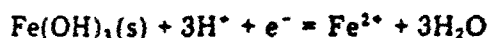


Fig. 1. Eh-pH diagram in the system K-U-V-O₂-H₂O-CO₂ at 25°C. Given: K = 10⁻³ M, U = 10⁻⁶ M (0.24 ppm) at mineral-solution boundaries; V = 10⁻⁶ M (0.1 ppm as VO₃), and P_{CO₂} = 10⁻³ atm. The figure is taken from Langmuir (1978).

muir, 1971). Under these conditions dissolved uranium will occur entirely as uranyl species. Groundwaters in contact with reactive pyrite or marcasite or organic matter, or which contain H_2S will generally lie near the bottom of the diagram within the uraninite field. At pHs above 6.5 to 7.0, usual values in sandstone-type deposits, nearly all of the dissolved uranium will occur as uranous [U(IV)] species. (See Langmuir, 1978, Fig. 2).

For these high and low redox conditions, respectively, exact Eh values are not needed to compute the saturation state of the water with respect to carnotite or uraninite. When plotted on a similar Eh-pH diagram the stability fields of tyuyamunite and coffinite are nearly identical to those of carnotite and uraninite, respectively, so the same generality applies to these minerals as well. Where intermediate Eh values are likely to exist however, their estimation is subject to serious error. For example, as one of three methods of estimating Eh, Runnells et al. (1980) used the measured pH and ferrous iron concentration, and the reaction:



and assumed a constant stability for solid $Fe(OH)_3$. However, Langmuir and Whittemore (1971) and Whittemore and Langmuir (1975) showed that the stability of $Fe(OH)_3$ can vary by nearly five orders of magnitude in a single aquifer system. The corresponding measured change in Eh was 360 mv. Eh can be inferred to be oxidizing from the presence of significant nitrate concentrations (high nitrate indicates uranyl species only), and can sometimes be estimated from the presence of redox-sensitive trace elements if such data is available.

CALCULATION OF MINERAL-SATURATION RESULTS

The measured and estimated chemical data were input into a modified and expanded version of the computer program WATEQF (Plummer et al., 1976) utilizing a DEC-SYSTEM 10 computer to perform the calculations. The thermodynamic data for U and V species and minerals in the program were taken from Langmuir (1978) except for the Gibbs free energy (ΔG_f°) of coffinite ($USiO_4$). Based upon the footnotes to table 1 in Langmuir (1978), ΔG_f° should equal -449.9 kcal/mol for coffinite instead of -452.0 kcal/mol, the value given in that table. The corresponding corrected enthalpy (ΔH_f°) value is -475.7 kcal/mol.

The modified WATEQF program computes ionic strength, activity coefficients, activities and concentrations of 370 dissolved species including complexes, and ion activity products of 239 minerals and other solid phases. The computed ion activity products of minerals are then divided by their respective solubility products. The logarithm of each quotient represents the saturation index (SI value) for that particular mineral. Positive numbers indicate the groundwater is supersaturated with respect to a particular mineral, whereas a value of zero or negative values represent saturated and undersaturated conditions, respectively.

THE THREE STUDY AREAS

In our study we examined the groundwater geochemistry of three sandstone-type uranium deposits. These included an oxidized deposit in the Catahoula Tuff in southern Texas, and two reduced deposits: one in the Oakville Sandstone in southern Texas, and a second in the Wasatch Formation in northeast Wyoming.

The Catahoula Tuff

Reports prepared as part of the NURE program (Nichols et al., 1977; Arendt et al., 1978) were used to obtain groundwater quality data for the Miocene Catahoula Tuff of southern and southeastern Texas (Fig. 2). Galloway (1979) describes the unit as an ash-rich, complexly interweaving fluvial system, with dip-oriented sand belts that tend to diverge from a point source northwest of the present outcrop. Fluvial channel-fill, crevasse splay, floodplain, and coastal lake facies are predominant. Montmorillonitic clay from the subsequently altered, abundant volcanic ash is a common constituent. The sand content of the Catahoula ranges from less than 10 to 50% of the total section.

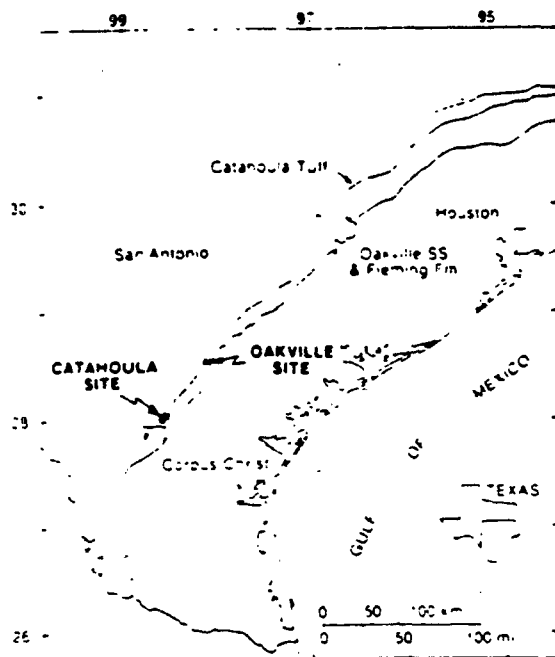


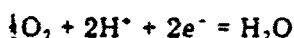
Fig. 2. Location of the Catahoula and Oakville Sites, within the Catahoula Tuff, and Oakville Sandstone and Fleming Formation, respectively. Groundwater quality data were collected from throughout the stippled portion of the Catahoula Tuff.

Uranium mineralization occurs as ragged and poorly developed roll-fronts along margins of the medium to fine-grained channel-fill and crevasse-splay facies. H_2S and HS^- from nearby faults apparently altered existent Fe-Ti oxyhydroxide minerals in the tuff, producing FeS_2 (chiefly pyrite), which was subsequently oxidized in part by U(VI)-bearing groundwaters, to produce a coffinite-pitchblende type ore (Goldhaber et al., 1978; Galloway, 1979). The ore is often Mo, Se, and V-enriched, especially in surface or shallow subsurface oxidized deposits (Weeks and Eargle, 1963). In the oxidized deposits the ore minerals are probably carnotite and tyuyamunite. Weeks and Eargle also identified autunite in the Catahoula Tuff. (We could not assess autunite solution-equilibria in this study because PO_4 groundwater analyses were lacking.)

Within the Catahoula, meteoric groundwater generally flows downdip (coastward) along ancient, fluvial channel networks, eventually to be discharged through thick, overlying aquitards, while saline formation water moves updip within the aquifer or along faults (Galloway, 1979). Some groundwater has been diverted to the surface due to stream incision of the outcrop (Galloway, 1977).

Groundwaters of the Catahoula Tuff are generally of the Ca or Na-Cl type. Calcium or Na- SO_4 waters are also occasionally present. Since analyses from the Catahoula covered a large geographic area (stippled in Fig. 2), the ranges of pH values and of dissolved species were large. The pH ranged from 6.5 to 10.7 (average 7.2), while total dissolved solids ranged from 325 to 4725 ppm (average 1529 ppm). Analyses from 12 wells widely distributed across the outcrop (stippled) area gave dissolved oxygen (DO) values ranging from 0.9 to 5.0 ppm. The DO data are consistent with the oxidized ore mineralogy.

The Eh of the groundwater was estimated from the average DO concentration of 3.0 ppm in these waters, and the reaction:



(Plummer et al., 1976), for which, at 25°C

$$Eh = 1.27 + 0.0148 \log [O_2] - 0.0592 \text{ pH}$$

In this expression $[O_2]$ is the DO concentration in moles per liter. This equation indicates that at a given pH, the theoretical Eh increases by only 11 mv as DO increases from 0.9 to 5 ppm. Thus, the average DO value of 3 ppm leads to an estimated Eh which is within 4–7 mv of the Eh value that corresponds to the highest and lowest measured DO values.

Computed carnotite and tyuyamunite saturation indices (SI values) and pH are plotted in Fig. 3, which is based on data from a profile that includes 15 wells trending parallel to strike (southwest to northeast) across the Catahoula site located in Fig. 2. The present groundwater flow direction is perpendicular to the plot. The obvious inverse relationship between pH and the SI curves reflects the fact that a major control on computed SI values is the measured pH, particularly because the DO is assumed constant. The figure

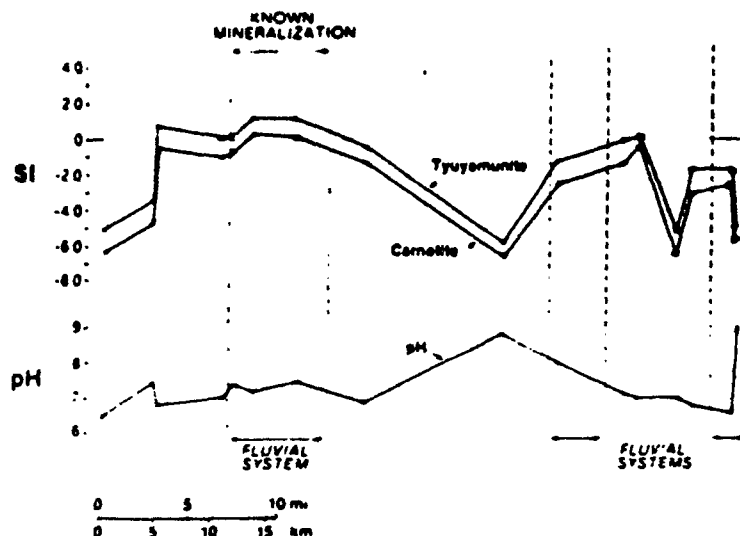


Fig. 3. Carnotite and tyuyamunite and saturation indices (SI values) and pH in groundwaters along a profile across the Catahoula Site.

shows SI values near or above saturation with respect to carnotite and tyuyamunite in a known zone of mineralization, and suggests additional ore should be sought further southwest and about 35 km to the northeast.

Commercially economic uranium deposits in the Catahoula Tuff in south Texas have been reported within and south of the Crystal City-Beeville Quadrangles. No significant discoveries have been described in the Seguin Quadrangle or in areas further north. Our data support these observations in that a number of groundwaters within and south of the Beeville Quadrangles were saturated or slightly supersaturated with respect to carnotite and tyuyamunite. Some of these localities correspond to areas of known mineralization, while others do not. In contrast, all Catahoula waters within the Seguin Quadrangle were undersaturated with respect to carnotite ($SI < -1.1$) and tyuyamunite ($SI < -0.6$).

Uranium and vanadium profiles across this same area (Fig. 4) offer the same general information, with the highest U and V concentrations found near zones of known or probable carnotite and tyuyamunite mineralization. In this groundwater U would be expected to occur as the uranyl di and tri-carbonate complexes, and V as $H_2VO_4^-$ and HVO_4^{2-} .

Profiles of Mo, As, and Se in Fig. 5 are less useful because these elements are not constituents of uranium minerals, and may have moved since their original deposition. They occur in the groundwater as the oxyanions MoO_4^{2-} , $HAsO_4^{2-}$, and SeO_4^{2-} (cf. Howard, 1977), too soluble to precipitate as specific minerals under these conditions. In general these oxyanions would tend to be adsorbed by positively charged ferric oxyhydroxides at low pH (below pH 5.5–8.5). Selenium concentrations are lowest in the ore zone, which is also

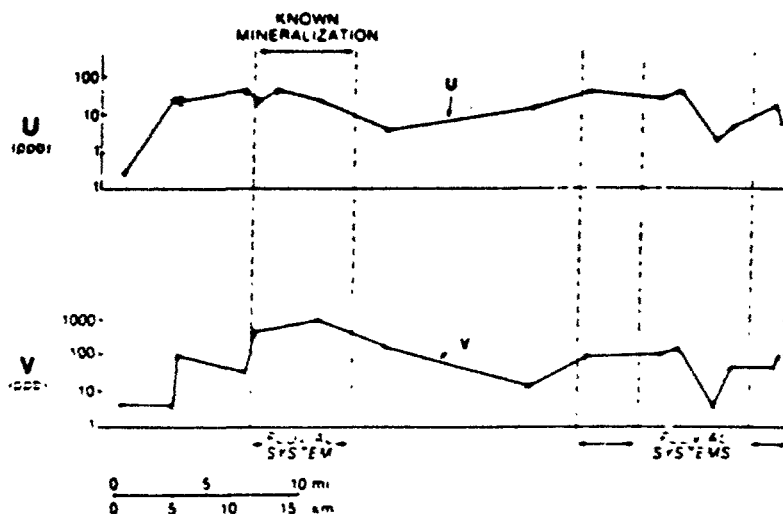


Fig. 4. Uranium and vanadium concentrations in groundwaters along a profile across the Catahoula Site.

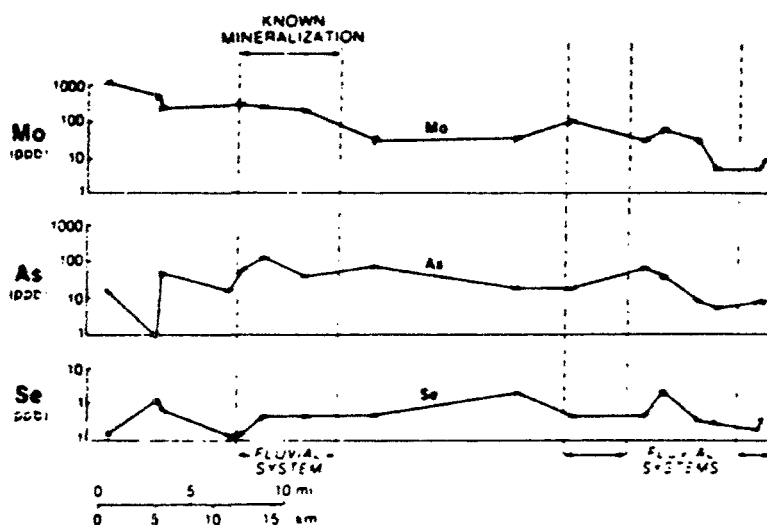


Fig. 5. Molybdenum, arsenic, and selenium concentrations in groundwaters along a profile across the Catahoula Site.

where the groundwater pH is lowest (6.5 to 7.5). However, Mo variations appear unrelated to uranium mineralization or to pH. Among these three elements, arsenic variations best mirror the saturation plots for carnotite and tyuyamunite. Unfortunately, our use of an estimated Eh to compute SI values, and especially the lack of mineralogical data from cores, makes geochemical interpretation of the concentration variations of these elements ambiguous.

The Oakville Formation

A second study area was selected within the Miocene Oakville Formation of southern Texas (Fig. 2). Fault-related deposits of coffinite and uraninite are present within a 6–18 m thick, basal section of fluvial, arkosic sandstone. Normal, down-to-the-coast growth faults which strike parallel to the present coastline are believed to have acted as conduits for reductant H_2S gas. The H_2S at different times may have been derived from the underlying Edwards Limestone or from other hydrocarbon-bearing formations (Goldhaber et al., 1979). Organic matter is sparse in the Oakville but 2 to 3% pyrite and ore-stage marcasite is ubiquitous. The basal sand is often calcite-cemented, especially along the fault. The ore occurs along a re-reduced roll front in sand and clay zones within the upthrown fault block (Goldhaber et al., 1979). Molybdenum probably forms a broad halo around the ore, with Se also present in locally anomalous amounts (Klohn and Pickens, 1970). The molybdenum is presumably within jordisite (amorphous MoS_2). The selenium may occur as native Se, ferroselite ($FeSe_2$), or in solid solution within the iron sulfides.

Hydrologic data from the site (Anonymous, 1978a, b) suggest that the present groundwater flow direction is northeasterly, with a gradient of from 1 to 3 m per kilometer. No leakage into adjacent aquifers or along the fault was detected during pumping tests conducted at the site. Groundwaters are mostly of the Ca or Na-Cl type, with Ca and Na- SO_4 predominant waters occasionally reported. Total dissolved solids ranged from 1692 to 2702 ppm (average about 2100 ppm). The pH ranged from 6.8 to 8.3 (average 7.4). The groundwater Eh was assumed constant at -120 mV. (Based on our own measurements in eight wells at the site, Eh ranged from -45 to -170 mV, and averaged -117 mV.) This average is consistent with the presence of H_2S in the eight wells we sampled, and with Eh values measured by Klohn and Pickens (1970) at the Exxon Felder Mine. For these Eh and pH conditions dissolved uranium is present chiefly as $U(OH)_3$.

Uraninite SI values were computed and plotted on a map of the Oakville site in Fig. 6. Values above zero indicate supersaturation with respect to crystalline uraninite $UO_2(c)$. However, the UO_2 , if present, is probably relatively fine-grained and poorly crystalline pitchblende which is more soluble than crystalline uraninite. This would account for the apparent supersaturations shown on the map. A map of coffinite SI values (not shown) has a very similar appearance to Fig. 6. It may be noted from the probable general location of the ore shown in Fig. 6, that the saturation contours provide a good reflection of the position and size of the ore zone. Uraninite saturation contours increase towards the ore body from as far away as 300 m (the limit of available well control), providing remote evidence of the ore.

Profiles of uraninite and coffinite SI values and of pH (Fig. 7) were drawn along the section labelled A-B in Fig. 6 which approximates the present



Fig 6 Map of the Oakville Site, showing well locations (•), contoured saturation indices of the groundwater with respect to uraninite, and locations of mineralized zones (cross-hatched areas). U and D denote up- and down-thrown fault blocks.

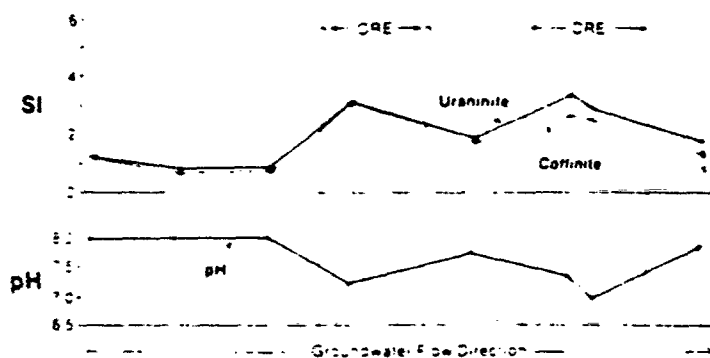


Fig 7 Coffinite and uraninite saturation indices and pH in groundwaters at the Oakville Site along profile A-B in Fig 6.

groundwater flow direction. Because Eh has been held constant, SI values plot as the inverse of pH. (Again, this is because Eh and pH are the chief controls on computed SI values.) As before, the lowest pH values occur within the ore zone.

Uranium and radium profiles were also plotted along section A-B (Fig. 8). Maximum U values are found in the ore zones, however the values are not as exceptionally high in these zones as are the SI values. Uranium concentrations elsewhere within the ore zone shown in Fig. 6 were as low as 1 ppb. Radium activity is high within the right (east) ore zone, however, no Ra maximum is evident in the left (west) ore zone. Radium anomalies may be displaced in the groundwater flow direction relative to the ore.

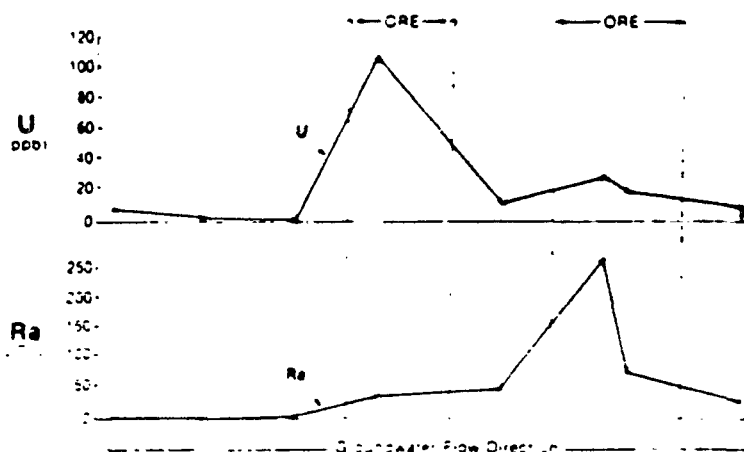


Fig. 8. Uranium concentrations and radium activity in groundwaters at the Oakville Site along profile A-B in Fig. 6.

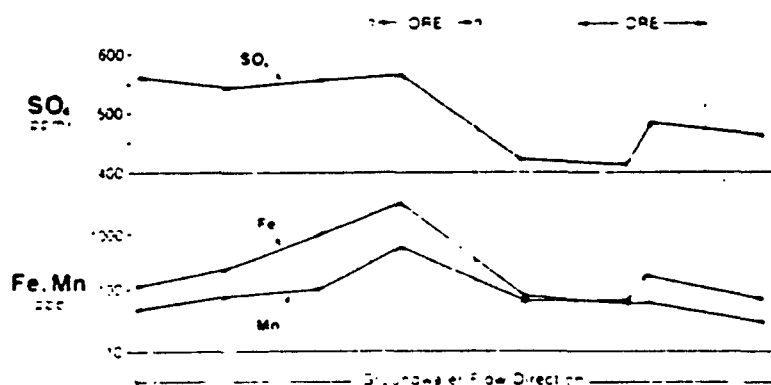


Fig. 9. Sulfate, iron and manganese in groundwaters at the Oakville Site along profile A-B in Fig. 6.

Profiles of SO_4 , Fe, and Mn in the groundwater were plotted in Fig. 9 along the same section. Maxima in these species occur within the ore zones, and are inverse to pH, except for Fe in the right (east) zone. This suggests that slight oxidation of pyrite, enriched in the ore, has led to the drop in pH and increases in Fe, Mn and SO_4 . A similar drop in pH due to oxidation of pyrite was suggested by Granger and Warren (1969) and DeVoto (1978) along classical roll-front deposits. The constancy of Fe in the right-hand ore zone is not readily explained.

Limited trace-element data is available for Oakville groundwaters, and many of the values are below detection limits. Variations in Cu, Mo, As, and Se are generally ambiguous. Copper and Mo have both maxima and minima

within the ore zone. Arsenic is inversely proportional to iron in one profile. These elements may be tied up in relatively insoluble sulfides and selenides and as native As or Se in the reduced sediments.

The Wasatch site

The third site studied was in northeast Wyoming on the west flank of the Powder River Basin (Fig. 10). Uranium mineralization occurs within an arkosic sandstone, approximately 30 m thick within the fluvial Wasatch Formation (Anonymous, 1978c). The sandstone unit, which includes several thin, interbedded claystones, is confined above and below by thick claystone-coal sequences. The ore minerals uraninite and coffinite occur in classical roll-front type deposits. Reduction to form the ore was by inorganic sulfur species and possibly also by carbonaceous material.

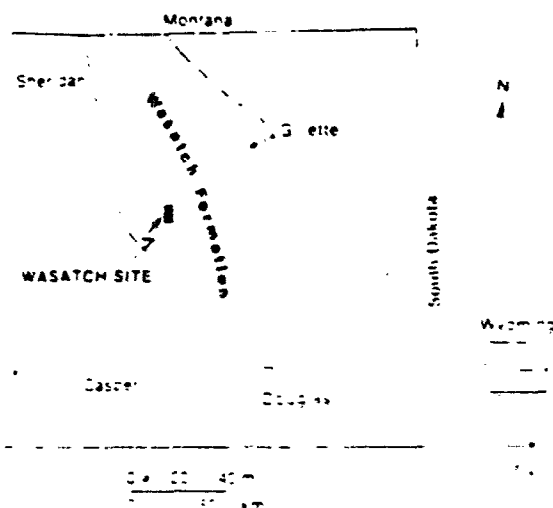


Fig 10 Location of the Wasatch Site in northeast Wyoming.

Descriptions of the groundwater hydrology at the site are ambiguous. Regional piezometric contour maps for the Wasatch Formation indicate a general north to northwest groundwater flow direction (Anonymous, 1978c). However, piezometric maps of the host sand suggest a due westward movement. Noses of the roll-fronts are oriented eastward in a direction reverse to present groundwater flow. Groundwater is of the Na-SO₄ type with a total dissolved solids concentration range from 340 to 629 ppm (average 425 ppm). The range in pH is from 8.3 to 10.5 (average 9.0). Groundwater Eh was assumed constant at -200 mV. This Eh is consistent with the ore mineralogy, and assures that all of the dissolved uranium is present as uranous species (chiefly as U(OH)₃).

A map of coffinite saturation values for the Wyoming site is shown in Fig. 11. The SI plot for uraninite (not shown) has a similar appearance. The probable location of ore indicated in the figure again correlates well with increasing SI values.



Fig. 11. Map of the Wasatch Site, showing well locations (•), contoured saturation indices with respect to coffinite, and the location of the mineralized zone (crosshatched area).

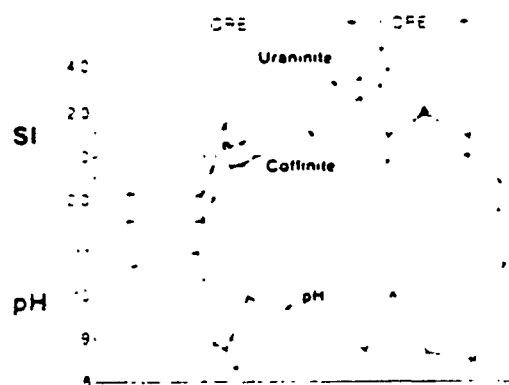


Fig. 12 Coffinite and uraninite saturation indices and pH in groundwaters at the Wasatch Site along profile A-B in Fig. 11.

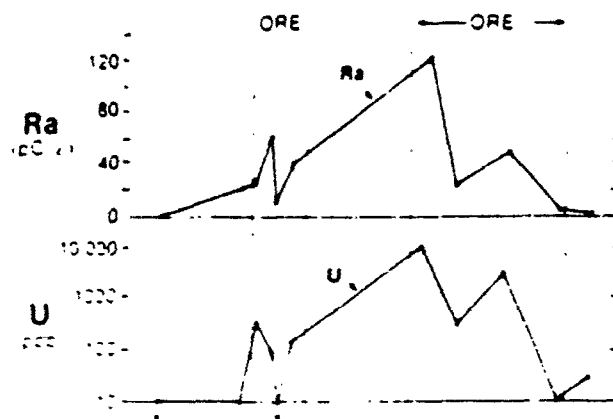


Fig 13 Uranium concentrations and radium activities in groundwaters at the Wasatch Site along profile A-B in Fig. 11. Vertical arrows denote uranium concentrations below the detection limit of 10 ppb.

A profile A-B in Fig. 11 is approximately perpendicular to the present groundwater flow direction (assumed to the northwest). A plot of uraninite and coffinite SI values and of pH along A-B in Fig. 12, shows that maximal SI values occur in the ore zones. Again, pH minima occur within the ore zones. As before this may reflect slight oxidation of pyrite present there. Profiles of U and Ra in Fig. 13 show that both elements vary approximately parallel to the saturation indices, with maxima in the ore.

As at the Oakville site, profiles of Fe and SO_4 in Fig. 14 are roughly parallel within mineralized zones, probably reflecting mild pyrite oxidation.

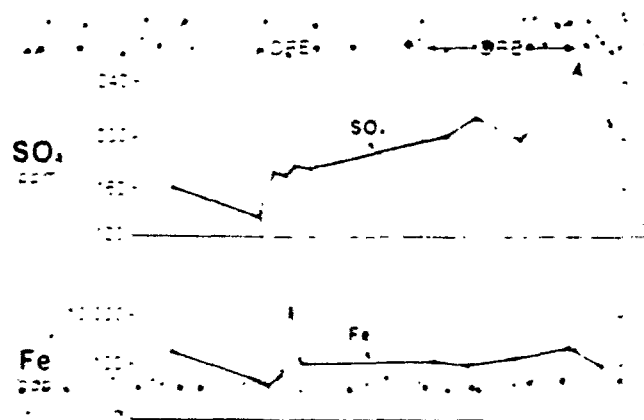


Fig 14 Sulfate and iron concentrations in groundwaters at the Wasatch Site along profile A-B in Fig. 11.

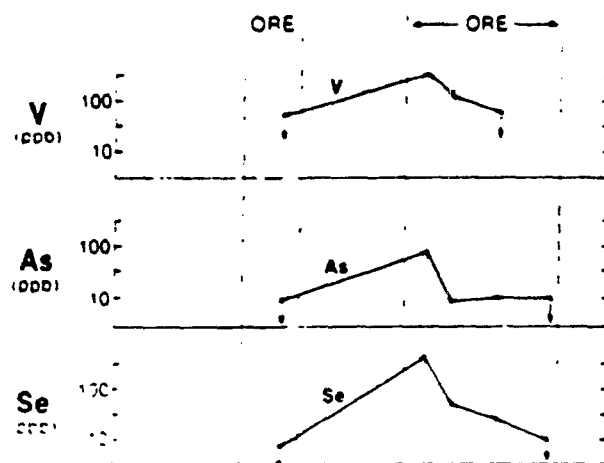


Fig. 15. Vanadium, arsenic, and selenium concentrations in groundwaters at the Wasatch Site along profile A-B in Fig. 11. Vertical arrows indicate that concentrations in the samples so labelled and in samples to the left and right of them, respectively, were below detection.

Most V, As, and Se concentrations are below detection limits (Fig. 15) and are thus relatively poor ore pathfinders at this site. High values are present in one ore body, but values are below detection in the other.

CONCLUSIONS AND DISCUSSION

Whether in oxidized or reduced sandstone-type deposits, uranium mineral-solution equilibria plotted in groundwater maps and profiles provide the most reliable index to the location of uranium deposits. Saturation index maps will often indicate the direction to ore at significant distances from the actual ore zone.

Uranium alone and vanadium in oxidized deposits of carnotite and tyuyamunite are apparently the next best indicators of ore among the species considered here. Uranium itself may be a useful regional pathfinder in oxidizing groundwaters, because of its great mobility under acid or alkaline conditions, but anomalies may be displaced by groundwater flow (Dyck, 1975; DeVoto, 1978). Uranium anomalies may even be entirely misleading as in northeastern Colorado and southeastern Wyoming (Childers, 1979) where large anomalies have been proven by drilling to be related to only traces of uranium mineralization. Childers (1979) also reports water samples that contain less than 2 ppb uranium from reduced aquifers in close proximity to ore bodies.

Radium data are useful, but Ra maxima may also be displaced from the ore zone by groundwater flow. Dyck (1975) reported that, because of its short half life (≤ 3.8 days) radon is best suited to use in semi-detailed geochemical exploration surveys. Radium mobility is limited to a large extent

by its adsorption onto Fe and Mn oxyhydroxides, clays, and organic matter (Rose and Komer, 1978), as well as coprecipitation with sulfates such as barite and probably also gypsum. In the analysis of groundwaters from over 300 wells in the Helsinki region, Asikainen and Kahlos (1979) reported large concentrations of U, Ra, and Rn, but found no significant correlation between U and Ra or U and Rn in individual well waters. Nevertheless, U, Ra, and Rn correlated strongly with each other on an areal basis.

Arsenic, Se and Mo are occasionally helpful ore pathfinders in oxidized deposits where they occur as soluble oxyanions, but they tend to be below detection limits in reduced sediments, except within some ore zones. In the latter case their low concentrations reflect the insolubility of native As and Se, and of sulfides and selenides containing these elements.

Utilizing saturation indices for uranium minerals in groundwater, although promising as an exploration tool, does have limitations. In this study it was necessary to estimate values for Eh and such species as K, Ca, Mg, Cl and Si. Obviously, accurate field-measured values for DO or Eh, and pH, and complete laboratory analyses of filtered samples for their dissolved species content would have been preferable. In spite of the estimates needed to compute mineral-saturation status in this study, maps of the saturation results were shown to be an excellent guide to the location of uranium ore bodies. We conclude that a similar approach could be taken elsewhere with equal success, utilizing groundwater analyses, and geologic and hydrologic data already available in reports provided by the NURE program and from industry.

ACKNOWLEDGEMENTS

We thank David Shuck and R.E. Iwanicki of Wyoming Mineral Corporation (WMC) for providing us with copies of reports prepared by WMC describing the geology, hydrology, and groundwater quality of the eastern portion of the Oakville Site (Anonymous, 1978a). We also thank Velu Annamalai of International Energy Corporation (IEC) for providing us with a similar report prepared by IEC describing the western portion of the Oakville Site (Anonymous, 1978b). R.E. Iwanicki of WMC and Velu Annamalai of IEC also graciously contributed additional information for the Oakville Site, and granted us permission to take field Eh and pH measurements, and to collect water samples from selected wells at that site. A review of the paper by Martin B. Goldhaber is greatly appreciated. This research was funded by the U.S. Department of Energy through Subcontract 79-361-E administered by the Bendix Field Engineering Corporation of Grand Junction, Colorado (Technical Monitor: Newton K. Stablein).

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REFERENCE #31

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

20 cm depth in an Oregon forest. It was found that oxalic acid was the chief low molecular weight organic acid in solution at the base of the humus layer. LAKIN (1979) noted that plant root exudates (as exemplified by those from wheat) contain oxalic and citric acids among others. He also showed that pine tree root exudates contain oxalic acid. It is likely, therefore, that citrate and oxalate are not uncommon in natural waters, although their concentrations will usually be much lower than those of humic substances.

EDTA was included in our study more as a 'type' ligand than as a specific constituent in natural waters. EDTA was chosen as an example of a multidentate organic chelating agent which forms an extremely strong complex with thorium. In fact, one EDTA group can completely satisfy the coordination requirements of the Th^{4+} ion. Communications with MALCOLM (1980) and WEBER (1980) suggest that EDTA may be equivalent in complexing ability to some aqueous humic species. Also, the present and proposed use of EDTA in cleansers and decontaminants in laboratory research and in large-scale decontamination operations involving radionuclides at nuclear facilities (cf. AYRES, 1970; MEANS *et al.*, 1978) makes its consideration here the more appropriate.

The wastes from clean-up operations at such facilities are treated and disposed of in a variety of ways, but quite often end up in near-surface tanks or trenches at radioactive burial sites (CERRE and MESTRE, 1970). There, agents including EDTA can

continue to be active for long periods of time, and so tend to be important in the long-term behavior of the trenches. While oxalate and citrate are eventually destroyed in biochemical processes, EDTA can persist for long periods in solution. MEANS *et al.* (1978) observed migration of ^{60}Co and other radionuclides, including thorium, from pits and trenches at the Oak Ridge National Laboratory burial site. The mobile species were identified as dissolved complexes of organic ligands, particularly EDTA. These authors found an EDTA concentration of about 98 ppb in well waters near disposal trenches at Oak Ridge.

THE THERMOCHEMICAL DATA

The thermodynamic data for thorium minerals and solutes at 25°C and 1 atm total pressure are given in Table 1. Table 2 lists thermodynamic data for non-thorium minerals and solutes used to derive the data in Table 1. Footnotes to the tables explain the data sources and methods of calculation. Such data was unavailable for citric acid or EDTA, or for their thorium complexes. However, stability constants for these species were available and are given in Table 3. The data in the tables are considered internally consistent.

A number of Russian authors have proposed that thorium carbonate complexes are important in alkaline waters (cf. SHCHERBINA and ABAKIROV, 1967). No thermodynamic data exist for such species, which in any case are unlikely to ever be significant. Thus, at alkaline pHs, thorium occurs chiefly as the strong neutral $\text{Th}(\text{OH})_4$ complex which will have little tendency to associate with carbonate ion.

In Fig. 1 are plotted entropies (S° values) of thorium

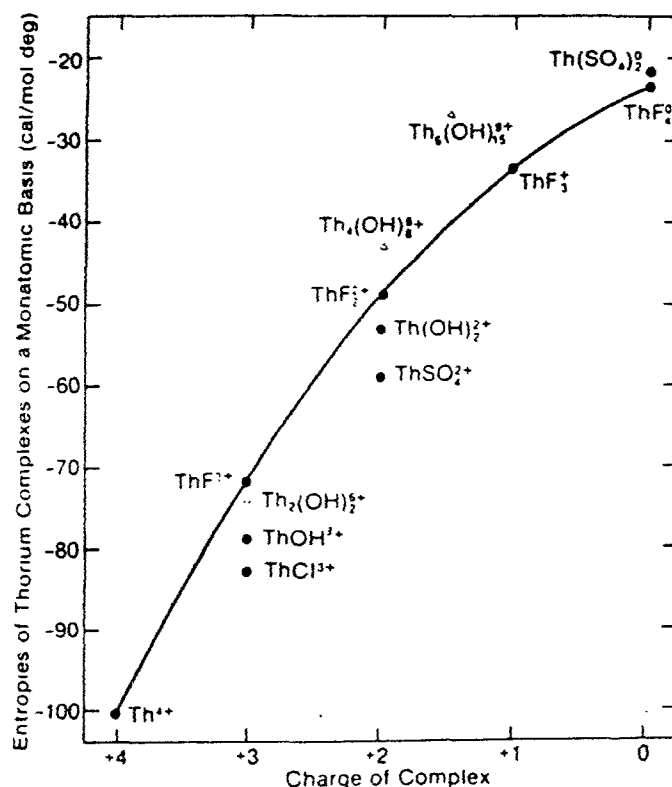


Fig. 1. Entropy vs valence for thorium ion and some thorium complexes on a monatomic basis.

The mobility of thorium in natural waters at low temperatures

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(Received 13 December 1979; accepted in revised form 7 July 1980)

Abstract—Thermodynamic properties of 32 dissolved thorium species and 9 thorium-bearing solid phases have been collected from the literature, critically evaluated and estimated where necessary for 25°C and 1 atm pressure. Although the data are incomplete, especially for thorium minerals and organic complexes, some tentative conclusions can be drawn. Dissolved thorium is almost invariably complexed in natural waters. For example, based on ligand concentrations typical of ground water ($\Sigma \text{Cl} = 10$ ppm, $\Sigma \text{F} = 0.3$ ppm, $\Sigma \text{SO}_4 = 100$ ppm, and $\Sigma \text{PO}_4 = 0.1$ ppm), the predominant thorium species are $\text{Th}(\text{SO}_4)_2$, ThF_2^+ , and $\text{Th}(\text{HPO}_4)_2$ below pH ≈ 4.5 ; $\text{Th}(\text{HPO}_4)_2$ from about pH 4.5 to 7.5; and $\text{Th}(\text{OH})_2^2$ above pH 7.5. Based on stability constants for thorium citrate, oxalate and EDTA complexes, it seems likely that organic complexes predominate over inorganic complexes of thorium in organic-rich stream waters, swamp waters, soil horizons, and waterlogged recent sediments. The thorium dissolved in seawater is probably present in organic complexes and as $\text{Th}(\text{OH})_2^2$. The tendency for thorium to form strong complexes enhances its potential for transport in natural waters by many orders of magnitude below pH 7 in the case of inorganic complexing, and below about pH 8 when organic complexing is important. The existence of complexes in addition to those formed with hydroxyl, is apparent from the fact that measured dissolved thorium in fresh surface waters (pH values generally 5–8) usually ranges from about 0.01 to 1 ppb and in surface seawater (pH = 8.1) is about 0.00064 ppb. This may be contrasted with the computed solubility of thorianite in pure water which is only 0.00001 ppb Th as $\text{Th}(\text{OH})_2^2$ above pH 5. Although complexing increases the solubility of thorium-bearing heavy minerals below pH 8, maximum thorium concentrations in natural waters are probably limited in general by the paucity and slow solution rate of these minerals and by sorption processes, rather than by mineral-solution equilibria.

INTRODUCTION

THE THERMODYNAMIC properties of dissolved thorium species and thorium minerals can be used to compute solution-mineral equilibria relations. These theoretical calculations tell much about the possible conditions for and extent of thorium mobility. Such information helps us to understand controls on thorium concentrations in ground water, and to predict the risk of thorium release in leachates from mining activity and radioactive wastes.

Thorium is found in nature only as a tetravalent cation. The element usually occurs in geologic materials as a trace constituent in solid solution in phosphate, oxide and silicate minerals, and sorbed onto clays and other soil colloids (HANSEN, 1970; BONDICETTI, 1974). It occurs as a major species only in a few rare minerals such as thorianite (ThO_2), and thorite (ThSiO_4). The former mineral is isomorphous with uraninite, the latter with zircon. For this reason a large part of naturally occurring thorium is found incorporated in the zircon structure. The chief source of thorium is monazite (Ce, La, Y, Th) PO_4 which usually contains 3–9% and up to 20% ThO_2 . Along

with zircon, monazite is concentrated with other resistant heavy minerals in stream and beach sands (RANKAMA and SAHAMA, 1958). Igneous UO_2 can form a complete solid solution with ThO_2 (ROGERS and ADAMS, 1969). Most Th host minerals are highly refractory to weathering and thorium has long been considered a very insoluble and immobile element in natural waters.

Data on dissolved thorium concentrations in natural waters is generally of poor quality or nonexistent. Few researchers have distinguished carefully or at all between the thorium in true solution, and that associated with suspended matter. For this reason it must usually be assumed that reported thorium concentrations are the maximum possible amounts dissolved.

MOORE and SACKETT (1964) measured 0.00064 ± 0.0002 ppb Th in two centrifuged Atlantic Ocean surface water samples. Because this is among the lowest seawater values reported (see ROGERS and ADAMS, 1969), and because the salinity and cations present in seawater tend to flocculate colloidal materials, this value should closely approximate the dissolved thorium present. SOMAYAJULU and GOLDBERG (1966)

Alcock and determined the activity of Th^{4+} in so that this value is approximately 10^{-20} . Moore and Sackett and Somayajulu and Goldberg reported Th concentrations in deep waters in the two oceans which were sometimes higher and sometimes lower than their surface ocean values.

KAMATH *et al.* (1964) obtained 1.1–2.7 ppb Th in five surface waters from non-uraniferous areas in India. The samples were passed through a $10\ \mu\text{m}$ filter before chemical analysis. MIYAKE *et al.* (1964) found 0.0087–0.045 ppb Th in ten Japanese river waters. Samples were passed through a $5\ \mu\text{m}$ filter before analysis. Based on a sampling of (filtered?) waters from five lakes and eleven streams in California, Nevada and Utah, THURBER (1965) reported 0.08–0.4 ppb Th with a few values <0.03 ppb.

DEMENTYEV and SYROMYATNIKOV (1965) measured Th in some spring and well waters in granite, weathered mantle and alluvium on granite. For 6, clear (unfiltered) ground waters, they obtained 0.2–0.9 ppb Th, whereas, 2 anomalous waters showed 7 and 40 ppb. Both OSMOND (1964) and KAMATH *et al.* (1964) studied thorium in ground waters of different temperatures. Osmond presumably analyzed unfiltered waters from carbonate rocks. Kamath and his coworkers passed their samples through a $10\ \mu\text{m}$ filter before analysis. Both studies reported Th concentrations increasing with ground water temperature. Osmond obtained 0.1 to 2 ppb Th in 4 waters having temperatures from about 25 to 91°C , respectively. KAMATH *et al.* noted that Th concentrations increased from 0.27 to 0.74 ppb in three spring waters with temperatures from 47 to 56°C , respectively.

In four surface and ground waters from areas near uranium mining, KAMATH *et al.* (1964) found 1.9–5.4 ppb Th. Based on the Russian literature, DROZDOVSKAYA and MEL'NIY (1968) concluded that as much as 0.1–10 ppb Th can occur in 'ground and mine waters'. Even higher Th concentrations (up to 38 ppm) have been recorded in seeps and ground waters associated with uranium mining and milling in the U.S.A. and Canada (see KAUFMAN *et al.*, 1976; MOFFETT and TELLIER, 1978). These situations are described in detail later in this paper.

Admittedly, much or most of the thorium reported in the above studies must be in suspended matter, not in true solution. Nevertheless, even the surface seawater value measured by MOORE and SACKETT (1964) exceeds the solubility of thorianite which is 0.00001 ppb Th as $\text{Th}(\text{OH})_4$ above pH 5. The available data therefore suggest that the concentration of Th in natural waters and therefore its mobility, is greatly increased by thorium complex formation.

The behavior of thorium in aqueous systems has been summarized by AMES and RAI (1978) and RAI and SERNE (1978). They have published solubility vs pH diagrams for thorianite, $\text{Th}(\text{OH})_4$, ThF_4 and thorium phosphate solids. However, their diagrams are

based on the assumption that H_2PO_4^- and HPO_4^{2-} are assumed to be inactive.

This report contains a collection and critical evaluation of the thermodynamic data for 9 solid and 32 dissolved thorium species including organic complexes. These data are then used to evaluate the distribution of thorium aqueous species and the solubility of thorianite at various ligand concentrations chosen to simulate those found in natural waters. The importance of thorium complexes to thorium mobility, thus far a matter of relative ignorance, has been estimated from these calculations. The report also includes a brief discussion of the role of sorption in thorium mobility.

THE CHOICE OF ORGANIC LIGANDS

The selection of inorganic ligands and corresponding thorium complexes for consideration was relatively straightforward in that thermodynamic data for these ligands and complexes was accessible. Also, typical concentrations of inorganic ligands in natural waters are well known. In contrast, both the identity and concentrations of organic ligands in such waters are poorly known.

The bulk of the organic material dissolved in natural waters has been described as humic substances. According to REUTER and PERDUE (1977) most of this material resembles the fulvic acids present in soils. A representative concentration of humic substances in surface waters may be about 10 mg/l (REUTER and PERDUE, *ibid.*), whereas the average concentration of humic substances in shallow ground waters may be nearer to 1 mg/l. Higher amounts are likely in most soil waters (100 mg/l, cf. McKEAGUE *et al.*, 1976). The acidic functional groups present in natural fulvic acids (carboxyl and phenolic hydroxyl groups) vary in both strength and relative abundance (SCHNITZER and KHAN, 1978). Consequently, stabilities of metal fulvic complexes vary with solution composition and with pH. This makes the use of such stability data impractical in model calculations. For this reason we have selected citrate ($\text{C}_6\text{H}_5\text{O}_7^{3-}$), oxalate ($\text{C}_2\text{O}_4^{2-}$) and EDTA ($\text{C}_{10}\text{H}_{12}\text{O}_8\text{N}_4^{4-}$) to exemplify the probable role of thorium-organic complexes in natural waters.

The occurrence of oxalate and citrate in soils and some natural waters supports our choice of these ligands. Oxalate is present in many plants and is released upon organic decomposition (LEAVENS, 1960). LIND and HEM (1975) reported oxalic and citric acids as two of the principal organic acids in forest soils and litter. GRAUSTEIN *et al.* (1977) identified whewellite and weddellite, calcium salts of oxalic acid, as common phases in the litter layer of soils. The same observers measured 900 ppb of dissolved oxalate at

measured by Moore and Sackett (1964) and by Somayajulu and Goldberg (1964) in deep waters in the two oceans which were sometimes higher and sometimes lower than their surface ocean values.

EDTA was included in ligand than as a specific complexing agent. EDTA was chosen as an organic chelating agent strong complex with the group can completely satisfy requirements of the Th^{4+} . MALCOLM (1980) and V. EDTA may be equivalent to some aqueous humic species. proposed use of EDTA in plants in laboratory research. contamination operations nuclear facilities (cf. AYRE makes its consideration by

The wastes from clean-ups are treated and disposed but quite often end up in trenches at radioactive MESTRE, 1970). There, a

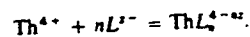
Table 1. Thermochemical data for thorium complexes and species. ΔH_f° are the free energy and enthalpy of formation from the elements. ΔG_f° are approximate or estimated values, or values derived from them. An asterisk indicates a solution at an ionic strength greater than 1.0 M.

Mineral or aqueous species	ΔH_f° (kcal/mol)	ΔG_f° (kcal/mol)	(cal/mol deg)	Source
$\alpha\text{-Th(c)}$	0	0	12.76	FUGER and OETTING (1976)
Th^{4+}	-183.8	-168.4	-101	FUGER and OETTING (1976)
ThOH^{3+}	(-246.2)	-220.7	-79°	FUGER and OETTING (1976)
Th(OH)_2^{2+}	(-306.5)	-272.3	-53°	FUGER and OETTING (1976)
Th(OH)_3^{+}	(-368.4)	(-322.5)	(-36)	See footnotes
Th(OH)_4^0	(-438.4)	-373.5	(-24)	See footnotes
$\text{Th}_2(\text{OH})_6^{2+}$	(-489.4)	-441.8	-147°	BAES and MESMER (1976)
$\text{Th}_3(\text{OH})_9^{+}$	(-1224)	-1098.3	-173°	BAES and MESMER (1976)
$\text{Th}_4(\text{OH})_{12}^0$	(-2019)	-1810.6	-160°	BAES and MESMER (1976)
$\text{Th}_5(\text{OH})_{15}^{+}$	(-449.5)	-408.0	(34)	See footnotes
Th(OH)_4	—	-273.2	—	See footnotes
$\text{ThO}_2(\text{c})$	-293.12	-279.35	15.59	CODATA (1977)
$\text{ThO}_2(\text{c})$ thorianite	—	—	—	WAGMAN et al. (1977)
$\text{ThSiO}_4(\text{c})$ thorite (huttonite)	—	—	(25.5)	See footnotes
ThF^{3+}	-265.15	-246.70	-72	WAGMAN et al. (1977)
ThF_2^{2+}	-346.1	-322.52	-49	WAGMAN et al. (1977)
ThF_3^{+}	-427.1	-396.2	-34	WAGMAN et al. (1977)
ThF_4^0	-508.1	-468.2	-24	WAGMAN et al. (1977)
ThF_5^{+}	-501.4	-478.9	33.95	WAGMAN et al. (1977)
$\text{ThF}_6(\text{c})$	(-682.2)	(-624.7)	(56.0)	WAGMAN et al. (1977)
$\text{ThF}_6 \cdot 2.5\text{H}_2\text{O}(\text{c})$	-223.7	-201.3	-83	WAGMAN et al. (1977)
ThCl^{3+}	—	-232.3	—	WAGMAN et al. (1977)
ThCl_2^{2+}	—	-264.8	—	WAGMAN et al. (1977)
ThCl_3^{+}	—	-295.6	—	WAGMAN et al. (1977)
ThCl_4^0	—	-261.6	(45.5)	WAGMAN et al. (1977)
ThCl_5^{+}	-283.6	-353.8	-59	WAGMAN et al. (1977)
$\text{ThCl}_6(\text{c})$	-397.2	-537.6	-22	WAGMAN et al. (1977)
ThSO_4^{2+}	-611.0	-716.6	—	WAGMAN et al. (1977)
$\text{Th(SO}_4)_2^0$	—	-891.8	—	See footnotes
$\text{Th(SO}_4)_3^{+}$	—	-444.1°	—	See footnotes
$\text{Th(SO}_4)_4^{2+}$	—	-444.9	—	WAGMAN et al. (1977)
$\text{ThH}_2\text{PO}_4^{+}$	—	-720.9	—	WAGMAN et al. (1977)
$\text{ThH}_3\text{PO}_4^0$	—	-443.5°	(-60)	See footnotes
$\text{Th(H}_2\text{PO}_4)_2^{+}$	(-450.3)	-720.2°	(-24)	See footnotes
ThHPO_4^0	(-762.3)	-992.1°	—	See footnotes
$\text{Th(HPO}_4)_3^{+}$	—	-952.5°	(89)	See footnotes
$\text{Th(HPO}_4)_2 \cdot 4\text{H}_2\text{O}(\text{c})$	(-1070)	-342.2	—	WAGMAN et al. (1977)
$\text{ThC}_2\text{O}_4^{2+}$	—	-515.9	—	WAGMAN et al. (1977)
$\text{Th(C}_2\text{O}_4)_2^{2-}$	—	-686.8	—	WAGMAN et al. (1977)

$\alpha\text{-Th(c)}$: S° supported by RAND (1975), CODATA (1977), and WAGMAN et al. (1977). Th^{4+} : Properties determined by FUGER and OETTING (1976), adopted by WAGMAN et al. (1977). ThOH^{3+} and Th(OH)_2^{2+} : S° values based on potentiometric measurements in 1 M NaClO₄ (BAES and MESMER, 1976). Th(OH)_3^{+} : ΔG_f° based on estimated K value (BAES and MESMER, 1976). S° estimated from Fig. 2. Th(OH)_4^0 : ΔG_f° based on K from BAES and MESMER (1976). S° estimated from Fig. 2. $\text{Th}_2(\text{OH})_6^{2+}$, $\text{Th}_3(\text{OH})_9^{+}$, and $\text{Th}_4(\text{OH})_{12}^0$: S° values based on potentiometric measurements in 1 M NaClO₄ (BAES and MESMER, 1976). Th(OH)_4 : ΔG_f° based on solubility of 'active' or 'hydrous' ThO₂ given by BAES and MESMER (1976). $\text{ThO}_2(\text{c})$: ΔG_f° based on solubility of 'active' or 'hydrous' ThO₂ given by BAES and MESMER (1976). S° estimated using Latimer's method with component entropies from NAUMOV et al. (1974). $\text{ThO}_2(\text{c})$: ΔG_f° = -273.2 based on solubility given by BAES and MESMER (1976). $\text{ThSiO}_4(\text{c})$: Huttonite is apparently the stable polymorph at all temperatures (ROGERS and ADAMS, 1969). S° is estimated as the sum of values for ThO₂(c) and SiO₂(c) quartz. $\text{ThH}_2\text{PO}_4^{+}$: ΔG_f° computed from $K = 10^{1.89}$ measured at $I = 2$ for: $\text{Th}^{4+} + \text{H}_2\text{PO}_4^{2-} = \text{ThH}_2\text{PO}_4^{+}$ (KATZ and SEABORG, 1957). ThHPO_4^0 through $\text{Th(HPO}_4)_3^{+}$: ΔG_f° values based on stability constants measured at $I = 0.35$ (MOSKVIN et al., 1967). S° values estimated from Fig. 2. $\text{Th(HPO}_4)_2 \cdot 4\text{H}_2\text{O}(\text{c})$: ΔG_f° based on solubility measured by MOSKVIN et al. (1967) at $I = 0.35$. S° estimated by Latimer's method with component entropies: S° (Th) = 15.9, S° (HPO₄) = 15 and S° (H₂O) = 10.7.

complexes vs their charge, where the entropy values are reasonably well known based on calorimetric or potentiometric measurements. This plot was used to estimate entropies of other monomeric complexes of the same valence. S° values for the OH polymers are also plotted for comparison purposes in Fig. 1, where S° (plotted) = S° polymer/x;

[x is the number of thorium atoms in the polymer, and the charge of complex (plotted) = charge of polymer x]. Table 3 lists the cumulative formation constants of thorium complexes with their formation reactions written



In this expression L is the number of ligand groups. The formation constants are listed in Table 3. The stable Th-OH complexes given by WAGMAN et al. (1977) have been adapted here. The description of the Th-OH complexes given by WAGMAN et al. (1977) who give only the dimer $\text{Th}_2(\text{OH})_6^{2+}$ species given by WAGMAN et al. (1977) respectively, in values.

Data are unavailable for H_2SiO_4^0 or H_3SiO_4^- . It is important in thermodynamic calculations. Writing the solution

permits us to compare Th(OH)_4 . Thus, $[\text{ThO}_2(\text{c})] = 10^{-4}$ reported in BAES and MESMER (1976) from the CC. The disparity between the full and the amorphous

Table 2. Thermodynamic data for thorium species at total pressure. Values in parentheses are estimated values (see footnotes).

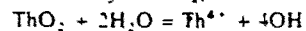
Mineral or aqueous species	ΔH_f° (kcal/mol)	ΔG_f° (kcal/mol)	S° (cal/mol deg)	Source
H ₂ (g)	0	0	31.207	CODATA (1976)
O ₂ (g)	0	0	49.005	CODATA (1976)
H ₂ O(l)	-68.315	-56.687	16.71	CODATA (1976)
OH ⁻	-54.977	-37.604	-2.560	CODATA (1976)
HF ⁰	-76.97	-71.68	22.09	PARKER <i>et al.</i> (1976)
F ⁻	-80.15	-67.34	-3.15	PARKER <i>et al.</i> (1976)
Cl ⁻	-39.933	-31.379	13.56	CODATA (1976)
PO ₄ ³⁻	-305.3	-243.5	-53	WAGMAN <i>et al.</i> (1968)
HPO ₄ ²⁻	-308.83	-260.34	-8.0	WAGMAN <i>et al.</i> (1968)
H ₂ PO ₄ ⁻	-309.82	-270.17	21.6	See footnotes
H ₃ PO ₄ ⁰	-307.92	-273.10	37.8	WAGMAN <i>et al.</i> (1968)
SiO ₂ (c) quartz	-217.66	-204.66	9.91	CODATA (1976)
SiO ₂ (am)	-215.33	-202.91	11.8	See footnotes
H ₄ SiO ₄ ⁰	-348.30	-312.58	45.1	See footnotes
H ₃ SiO ₄ ⁻	-342.18	-299.18	20.7	BUSEY and MESMER (1977)
H ₂ SiO ₄ ²⁻	—	-281.31	—	BAES and MESMER (1976)
SO ₄ ²⁻	-217.40	-177.95	4.50	CODATA (1977)
HSO ₄ ⁻	-212.16	-180.67	31.2	See footnotes
H ₂ C ₂ O ₄ ⁰	-194.7	-168.6	44.4	See footnotes
HC ₂ O ₄ ⁻	-195.6	-166.93	35.7	WAGMAN <i>et al.</i> (1968)
C ₂ O ₄ ²⁻	-197.2	-161.1	10.9	WAGMAN <i>et al.</i> (1968)

H₂PO₄⁻: WAGMAN *et al.* (1968) give $\Delta G_f^\circ = -260.17$ kcal/mol, which is apparently a misprint. The tabulated value is consistent with well established stability constant data and with the tabulated ΔH_f° and S° values. SiO₂(am): ΔG_f° based on the stability of amorphous silica from 0-250°C, written SiO₂(am) + 2H₂O = H₄SiO₄⁰, for which log [H₄SiO₄⁰] molar = -0.259-731/T(K) (FOURNIER, 1976). KILDAY and PROSEN (1973) measured $\Delta H_f^\circ = 2.22 \pm 0.07$ kcal/mol for SiO₂(quartz) = SiO₂(am) from which $\Delta H_f^\circ = -215.33$ and combined with ΔG_f° from FOURNIER (1976), $S^\circ = 11.8$ cal/mol deg. The temperature function of FOURNIER (1976) leads to $S^\circ = 10.5$ cal/mol deg. H₄SiO₄⁰: Data based on log[H₄SiO₄⁰] molar = 0.394-1310/T(K) from 25-250°C for quartz solubility written SiO₂(quartz) + 2H₂O = H₄SiO₄⁰ (MOREY *et al.*, 1962). HSO₄⁻: ΔH_f° , ΔG_f° and S° adjusted relative to values for SO₄²⁻ assuming properties for the reaction H⁺ + SO₄²⁻ = HSO₄⁻ unchanged from properties computed using values given by WAGMAN *et al.* (1968). H₂C₂O₄⁰: MARTELL and SMITH (1977) list log K = 1.252 and $\Delta H_f^\circ = 0.9 \pm 0.1$ kcal/mol for H⁺ + HC₂O₄⁻ = H₂C₂O₄⁰. The data for H₂C₂O₄⁰ are computed from this information and tabulated results for HC₂O₄⁻ and C₂O₄²⁻. The properties of H₂C₂O₄⁰ listed by Wagman *et al.* are in error.

In this expression L is the ligand of valence z and n is the number of ligand groups in the complex. In some cases, for comparison purposes, more than a single source and constant are listed in Table 3. Sources of the data chosen for inclusion in Table 1 are indicated in the 'Source' column of that table. The stability constants and entropies of the Th-OH complexes given by BAES and MESMER (1976) have been adapted here. These authors provide a more complete description of the Th-OH system than do WAGMAN *et al.* (1977), who give only data for ThOH³⁺, Th(OH)₂²⁺ and the dimer Th₂(OH)₄²⁺. Entropies of the first two of these species given by Wagman *et al.* are -82 and -52 cal/mol deg respectively, in good agreement with the tabulated values.

Data are unavailable for complexes between Th⁴⁺ and H₄SiO₄⁰ or H₃SiO₄⁻, however, such complexes are likely to be important in acid, silica-rich waters. No empirical thermodynamic values are available for thorite.

Writing the solubility of ThO₂(thorianite) as



permits us to compare the stabilities of ThO₂ and Th(OH)₄. Thus, K_{sp} [Th(OH)₄] = 10^{-46.6} and K_{sp} [ThO₂(c)] = 10^{-44.7} based on solubility measurements reported in BAES and MESMER (1976) and 10^{-44.2} computed from the CODATA (1977) ΔG_f° value for thorianite. The disparity between these last 2 values is disturbing. However, the full range of K_{sp} values of 7.6 log units separating the amorphous and crystalline Th oxides and hy-

droxides is perfectly possible for a quadrivalent cation such as Th⁴⁺. Approximate solubilities of Th(OH)₄ and ThO₂(c) as a function of temperature to near 300°C are reported by ROBINS (1967).

DISSOLVED THORIUM SPECIES

Cumulative formation constants of the complexes vs ligand number are plotted in Fig. 2. In general, the stronger the 1:1 complex, the more likely that an important 1:2 and 1:3 complex will also exist. Weak 1:1 complexes as are formed with Cl⁻, NO₃⁻, and H₃PO₄⁰ indicate that higher order complexes will also be unimportant. Strong complexes are formed with H₂PO₄⁻, SO₄²⁻ and F⁻. The strongest common inorganic complexes are formed with OH⁻ and HPO₄²⁻. The organic species, oxalate, citrate and especially EDTA, form strong complexes with thorium.

Application of the stability constant data shows that thorium in natural waters is usually complexed with sulfate, fluoride, phosphate, hydroxide and organic anions. These complexes greatly increase the solubility of thorium minerals and the mobility of thorium in surface, soil and ground waters. To

and read
Co. Kramel

Table 1. Cumulative formation constants of Th complexes. Parentheses denote estimated values. Where more than one complex is shown, an asterisk indicates the value chosen for inclusion in Table 1.

Complex	Log K	<i>l</i>	Source
ThOH ³⁺	10.8*	0	BAES and MESMER (1976)
	10.2	0	WAGMAN <i>et al.</i> (1977)
Th(OH) ₂ ⁺	21.07*	0	BAES and MESMER (1976)
	21.23	0	WAGMAN <i>et al.</i> (1977)
Th(OH) ₃	(30.3)	0	BAES and MESMER (1976)
Th(OH) ₄	40.1	0	BAES and MESMER (1976)
ThF ³⁺	8.44	0	BAUMAN (1970)
	8.03*	0	WAGMAN <i>et al.</i> (1977)
ThF ₂ ⁺	15.06	0	BAUMAN (1970)
	14.25*	0	WAGMAN <i>et al.</i> (1977)
ThF ₃	19.81	0	BAUMAN (1970)
	18.93*	0	WAGMAN <i>et al.</i> (1977)
ThF ₄	23.17	0	BAUMAN (1970)
	22.31*	0	WAGMAN <i>et al.</i> (1977)
ThCl ³⁺	1.35	0	See footnotes
	1.09*	0	WAGMAN <i>et al.</i> (1977)
ThCl ₂ ⁺	0.80	0	WAGMAN <i>et al.</i> (1977)
ThCl ₃	1.65	0	WAGMAN <i>et al.</i> (1977)
ThCl ₄	1.26	0	WAGMAN <i>et al.</i> (1977)
ThHPO ₄ ²⁺	10.8	0.35	MOSKVIN <i>et al.</i> (1967)
Th(HPO ₄) ₂ ⁰	22.8	0.35	MOSKVIN <i>et al.</i> (1967)
Th(HPO ₄) ₃ ⁻	31.3	0.35	MOSKVIN <i>et al.</i> (1967)
ThH ₂ PO ₄ ⁺	4.52	0	WAGMAN <i>et al.</i> (1977)
ThH ₂ PO ₄ ₂ ⁺	8.88	0	WAGMAN <i>et al.</i> (1977)
ThH ₃ PO ₄ ⁺	1.91	2	KATZ and SEABORG (1957)
ThSO ₄ ²⁺	(6.17)	0	See footnotes
	5.45*	0	WAGMAN <i>et al.</i> (1977)
ThSO ₄ ₂ ⁰	(9.59)	0	See footnotes
	9.73*	0	WAGMAN <i>et al.</i> (1977)
ThSO ₄ ₃ ⁻	(10.34)	0	See footnotes
	10.50*	0	WAGMAN <i>et al.</i> (1977)
ThSO ₄ ₄ ⁻	(8.27)	0	See footnotes
	8.48*	0	WAGMAN <i>et al.</i> (1977)
ThNO ₃ ³⁺	0.94	0	WAGMAN <i>et al.</i> (1977)
Th(NO ₃) ₂ ⁺	1.97	0	WAGMAN <i>et al.</i> (1977)
ThC ₂ O ₄ ²⁺	9.30	0	WAGMAN <i>et al.</i> (1977)
ThC ₂ O ₄ ₂ ⁰	18.54	0	WAGMAN <i>et al.</i> (1977)
ThC ₂ O ₄ ₃ ⁻	25.73	0	WAGMAN <i>et al.</i> (1977)
ThC ₄ H ₄ O ₇ ⁺	13.00	0.5	See footnotes
ThC ₄ H ₄ O ₇ ₂ ⁻	20.97	0.5	See footnotes
ThEDTA ⁰	25.30	0.1	See footnotes
ThHEDTA ⁻	17.02	0.1	See footnotes

ThCl³⁺: At *l* = 0.5 KATZ and SEABORG (1957) give $K_1 = 2.24$ for $\text{Th}^{4+} + \text{Cl}^- = \text{ThCl}^{3+}$. Correction to *l* = 0, assuming the same activity coefficient behavior as observed for ThOH³⁺ in perchlorate media (AHR- LAND *et al.*, 1973), gives $K_1 = 10^{1.35}$. ThSO₄²⁺ through Th(SO₄)₄⁻: ALLEN and McDOWELL (1963) measured $\log K_3 = 0.75$ and $\log K_4 = -2.07$ for the successive stability constants of Th(SO₄)₃⁻ and Th(SO₄)₄⁻ respectively at *l* = 0. AHR- LAND *et al.* (1973) give $\log K_2 = 2.42$ for *l* = 2. Rough correction to *l* = 0 gives $\log K_2 = 3.42$. These data lead to stepwise differences of $\log (K_3/K_4) = 2.82$ and $\log (K_2/K_3) = 2.67$. Assuming the average of 2.75 applies to $\log (K_1/K_2)$ leads to $\log K_1 = 6.17$ at *l* = 0. Values based on these calculations are shown in parentheses in Table 1. Th-citrate: NEBEL and URBAN (1966) as reported in SILLEN and MARTELL (1971). Th-EDTA and Th-HEDTA: BUTTARI and ANDERLOGG (1967), as reported in SILLEN and MARTELL (1971).

properly judge the relative importance of these complexes, we must compare their amounts in solutions that contain typical concentrations of the complexing ligands.

The thermochemical data in Tables 1-3 have been used to construct the diagrams in Figs 2-11. Math-

ematical methods needed to develop the percentage distribution of complexes in Figs 3-8 and the mineral solubility diagrams in Figs 9-11 are described by BUTLER (1964). Creation of the more complicated diagrams was accomplished by programming the calculations on an IBM 370/168 computer. The diagrams

Fig. 2. Cumulative

are presented in terms of assuming ionic strength defined by the total plot.

Distribution of aqueous

The distribution of different water components and the relative importance of typical natural wa-

Fig. 3. Di-

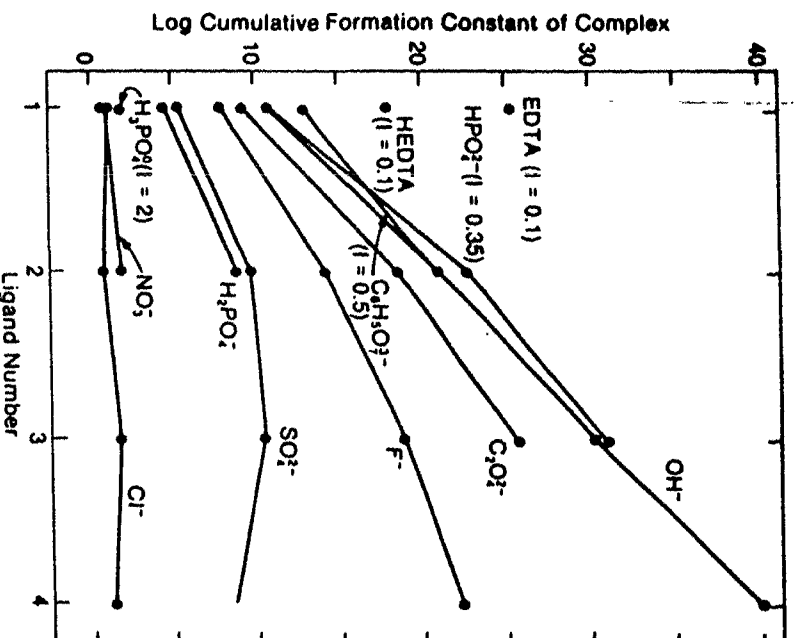


Fig. 2. Cumulative formation constants of monomeric Th^{4+} complexes at 25°C plotted against their ligand numbers. Constants are for zero ionic strength except where indicated.

are presented in terms of Th species concentrations, assuming ionic strengths and activity coefficients defined by the total concentrations specified for each plot.

Distribution of aqueous species

The distribution of aqueous thorium species for different water compositions was calculated to establish the relative importance of the various complexes in typical natural waters. Since the degree of thorium

complexation is independent of its total concentration when a complexing ligand is in large excess over thorium, these distribution diagrams apply to a range of thorium concentrations depending upon which ligand is of interest. The calculations were made for 0.01 ppb total thorium, a concentration much smaller than that for any of the anions.

Figure 3 shows the range of predominance of dissolved thorium species in pure water. Free Th^{4+} ion dominates at pH's below 3. From about pH 3 to 4.5,

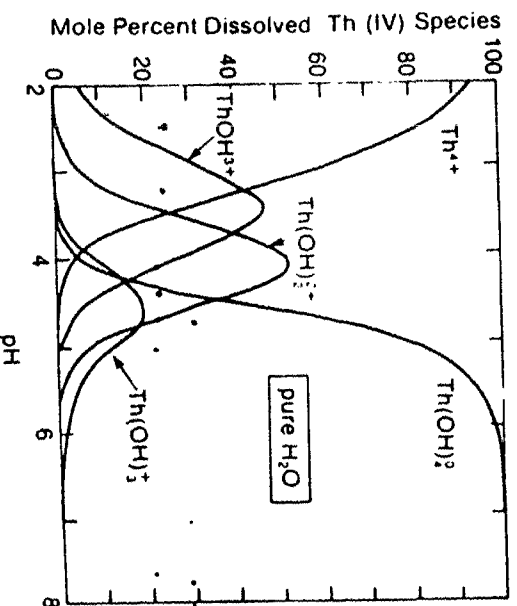


Fig. 3. Distribution of thorium-hydroxy complexes vs pH at 25°C with $\Sigma\text{Th} = 0.01$ ppb in pure water.

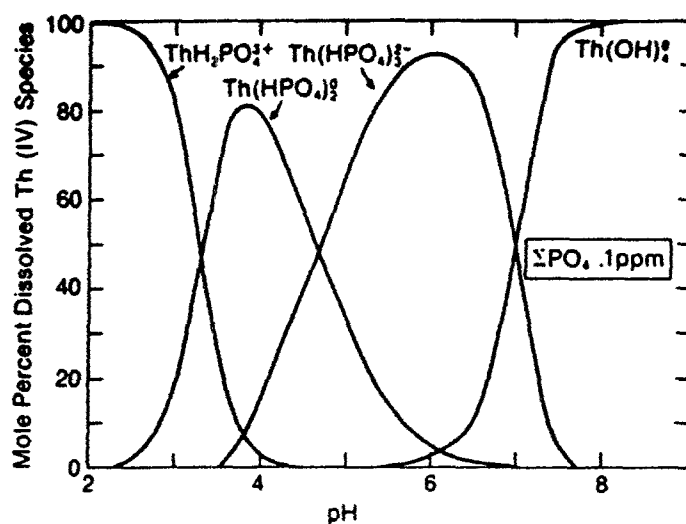


Fig. 6. Distribution of thorium-hydroxy and phosphate complexes vs pH at 25°C with $\Sigma\text{Th} = 0.01 \text{ ppb}$ and $\Sigma\text{PO}_4 = 0.1 \text{ ppm}$.

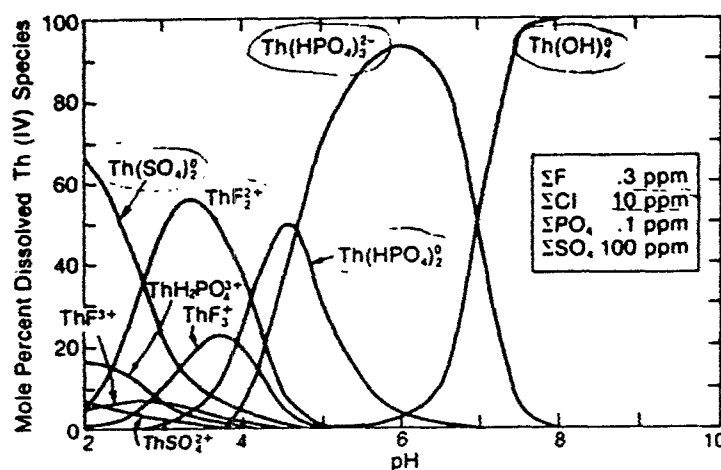


Fig. 7. Distribution of thorium complexes vs pH for some typical ligand concentrations in ground water at 25°C with $\Sigma\text{Th} = 0.01 \text{ ppb}$.

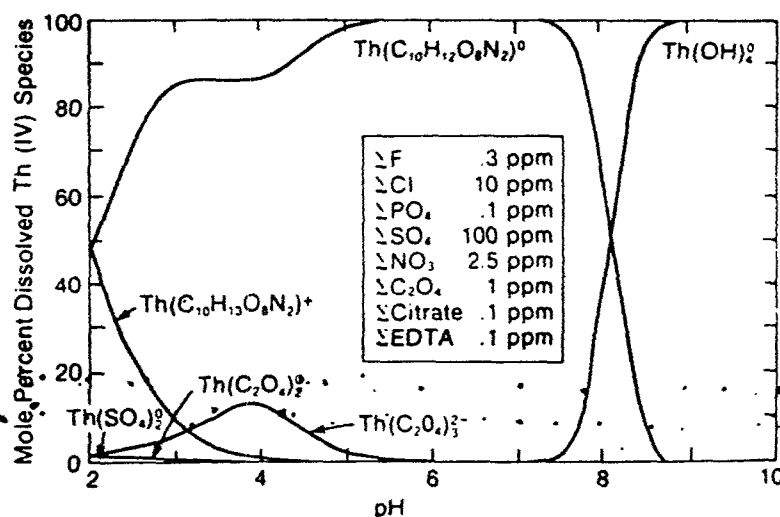


Fig. 8. Distribution of thorium complexes vs pH in a solution containing inorganic and organic species at the concentrations indicated and 25°C with $\Sigma\text{Th} = 0.01 \text{ ppb}$.

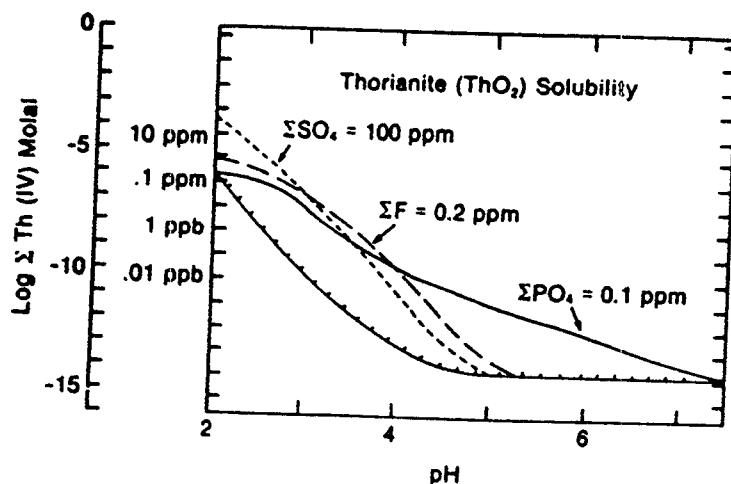


Fig. 9. The effect of thorium-sulfate, fluoride and phosphate complexing on the solubility of thorianite, $\text{ThO}_2(\text{c})$, as a function of pH at 25°C. The cross-hatched curve denotes the solubility of thorianite in pure water. The curves indicating thorianite solubility as affected by complexing have been constructed assuming each ligand present in the absence of the others.

could not be considered because of a lack of thermodynamic data.

The individual effects of Cl^- and NO_3^- ions on thorianite solubility are negligible. Even in sea water (pH 8.1) with $\text{Cl}^- = 19,000$ ppm, Th-Cl^- complexing is insignificant relative to hydroxyl complexing. For nitrate concentrations up to 1000 ppm, Th-NO_3^- complexes never approach 1% of total Th-OH^- complexes. Sulfate increases thorianite solubility below pH 5, as shown in Fig. 9. Dissolved thorium is increased by three orders of magnitude at pH 3 in the presence of 100 ppm total sulfate alone in solution. However, except in acid mine water and raffinates, and acid sulfate soils and H_2SO_4 leachates from hydrothermal uranium ores, increases in ThO_2 solubility due to sulfate complexing would generally be unimportant. Even in seawater with $\text{SO}_4 = 2650$ ppm, sulphate complexes are insignificant relative to

hydroxyl complexes. Fluoride also increases ThO_2 solubility in the low pH range (Fig. 9) and does so significantly more than does sulfate alone at the same concentration. Thus, 2 ppm total fluoride can increase dissolved thorium from 10^{-4} ppb to 10 ppb at pH 4. Phosphate can increase thorianite solubility up to pH 7 (Fig. 9). For example, at pH 4, 0.1 ppm total phosphate increases ThO_2 solubility by a thousand-fold.

In general, organic ligands greatly enhance the solubility of thorianite at pH's below 7. As shown in Fig. 10, 1 ppm total oxalate increases ThO_2 solubility by 10^7 times at pH 4. Only 1 ppb total EDTA (not shown in Fig. 10) similarly increases thorianite solubility by nearly 10^6 times at pH 5. Corresponding calculations for citrate show it to be a less important complexer than oxalate or EDTA. The final solubility diagram in Fig. 11 depicts the effect of the combined

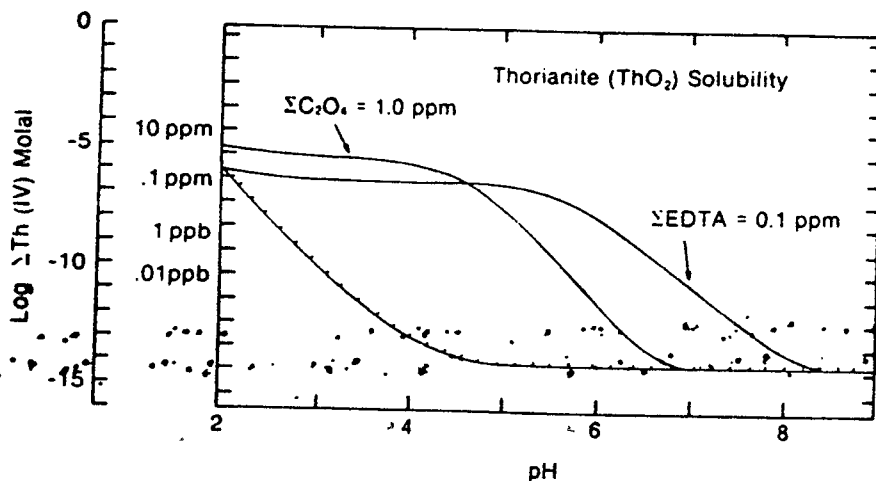


Fig. 10. The effect of thorium-oxalate vs thorium EDTA complexing on the solubility of thorianite, $\text{ThO}_2(\text{c})$, as a function of pH at 25°C. The cross-hatched curve denotes the solubility of thorianite in pure water. The curves indicating thorianite solubility as affected by complexing have been constructed assuming each ligand present in the absence of the other.

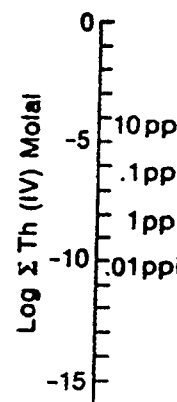


Fig. 11. The effect of thorium-chloride complexing on the solubility of thorianite, $\text{ThO}_2(\text{c})$, as a function of pH at 25°C. The curve indicates thorianite solubility in a solution of $\Sigma\text{Cl} = 10$ ppm.

solution compositions. ThO_2 organic ligands present is increased in magnitude above the purely inorganic ligands at pH 5. The range of increased solubility is pH 8, whereas inorganic ligands increase solubility only below pH 7.

Qualitative calculations by BONDIIETI (1979) suggest that in the presence of thorium phosphate solids may be more soluble than thorianite above pH 6. However, these results were obtained without consideration of such a conclusion is tenuous.

SORPTION OF THORIUM

Most studies of thorium-sorption on minerals have at best led to qualitative conclusions. Much of such work has involved measurement of the distribution coefficient, K_d , defined as the ratio of concentration on the solid weight of the solid to the concentration in the solution. Such values have rarely been calculated with adequate consideration of the mineralogy and surface chemistry of the solid, including its specific surface area and chemistry (cf. DAHLMAN *et al.*, 1979, pp. 2-30) summarize some of the deficiencies in such work. Nevertheless, the information on the sorption behavior obtained is useful.

The adsorption of thorium on organic matter increases with increasing pH. Adsorption is practically complete at pH 6.5 (BONDIIETI, 1979). The distribution of adsorption and a tendency for adsorption to be favored when strongly complexing ligands such as fulvic or citric acid are present (BONDIIETI, *ibid.*). In natural systems, thorium adsorption is less complete than for other actinides onto solid humic substances. Comparison of thorium-organic complexing with thorium-sorption on minerals is needed.

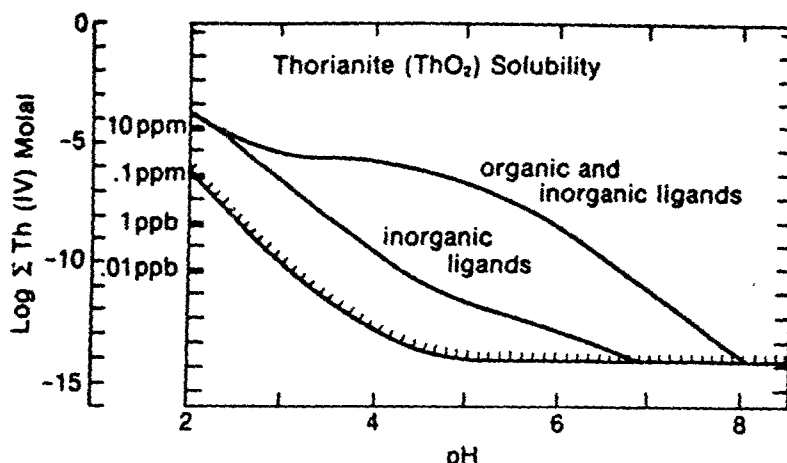


Fig. 11. The effect of thorium complexing on the solubility of thorianite. $\text{ThO}_2(\text{c})$ vs pH at 25°C in a solution of $\Sigma\text{Cl} = 10$ ppm, $\Sigma\text{NO}_3 = 2.5$ ppm, $\Sigma\text{SO}_4 = 100$ ppm, $\Sigma\text{F} = 0.3$ ppm, $\Sigma\text{PO}_4 = 0.1$ ppm, $\Sigma\text{oxalate} = 1$ ppm, $\Sigma\text{citrate} = 0.1$ ppm and $\Sigma\text{EDTA} = 0.1$ ppm.

solution compositions. ThO_2 solubility with the organic ligands present is increased five orders of magnitude above the purely inorganic solubility at pH 5. The range of increased solubility extends up to pH 8, whereas inorganic ligands alone significantly effect solubility only below pH 7.

Qualitative calculations by AMES and RAI (1978) suggest that in the presence of calcium phosphates, thorium phosphate solids may be even less soluble than thorianite above pH 6. However, because their results were obtained without considering complexes such a conclusion is tenuous.

SORPTION OF THORIUM

Most studies of thorium sorption onto natural materials have at best led to qualitative results. The bulk of such work has involved measurement of a distribution coefficient, K_d , defined as the radionuclide concentration on the solid/weight of solid, divided by the radionuclide concentration in solution volume. Such values have rarely been determined with adequate consideration of the detailed mineralogy and surface chemistry of sorbent phases, or of the solution, including its speciation and reaction chemistry (cf. DAHLMAN *et al.*, 1976). AMES and RAI (1979, pp. 2-30) summarize some of the common deficiencies in such work. Nevertheless, some useful information on the sorption behavior of thorium has been obtained.

The adsorption of thorium onto clays, oxides and organic matter increases with increasing pH and is practically complete at pH 6.3 (BONDIETTI, 1974). Inhibition of adsorption and a tendency towards desorption is favored when strongly complexing organic ligands such as fulvic or citric acids, or EDTA are present (BONDIETTI, *ibid.*). In neutral to acid waters, thorium adsorption is less complete onto clays than onto solid humic substances. Conversely, the formation of thorium-organic complexes leads to more

complete desorption of thorium from clay than from organic matter.

Because thorium ion is largely hydrolyzed at pHs above 3.2, it is evident that the hydroxy complexes are involved in the sorption process and that aquothorium ion (Th^{4+}) is not as readily adsorbed. This will in part reflect the fact that Th^{4+} must compete with protons for exchange sites (cf. DAVIS and LECKIE, 1979). VYDRA and GALBA (1967) found that only minor sorption of thorium onto silica gel occurred at pHs below 2, but that sorption increased with pH to maximum values at about pH 5.5. Employing a mixed quartz-illite soil as sorbent, RANCON (1973) measured a K_d value of 5 ml/g at pH 2, but K_d rose to 5×10^5 ml/g at pH 6. With a quartz-illite-calcite-organic matter soil, RANCON found that K_d decreased from 10^6 ml/g at pH 8 to 100 ml/g at pH 10. This reduction in sorption with increased pH was attributed to dissolution of soil humic acids and the formation of thorium-organic complexes.

Unfortunately, the published research on thorium adsorption to date has been insufficiently detailed to allow more than qualitative application of such results to complex natural systems. Distribution coefficients have no accurate predictive value outside the laboratory systems employed for their measurement. Future research should instead be directed towards measurement of thermodynamically meaningful adsorption constants, which require a relatively complete knowledge of the activities of dissolved species including complexes, and of the surface properties of sorbent phases (cf. DAVIS and LECKIE, 1979; LANGMUIR and OZSVATH, 1980).

RELATIONSHIP BETWEEN THE MOLAR CONCENTRATION OF THORIUM AND ITS RADIOACTIVITY

The radioactive isotopic concentration of a given element in water is usually determined from the

water's radioactivity reported in pico-Curies (10^{-12} Ci) per liter. To convert the radioactivity measurement to molar concentration per liter, the pico-Curies value must first be converted to decays per second (dps), where $1 \text{ pCi} = 0.037 \text{ dps}$. From the radioactive decay law, the expression $T = (\ln 2)/\lambda$ is derived, where T is the half-life of the radionuclide in seconds and λ is the probability that the nuclide will decay within a given time. By definition: Disintegration rate (D) = λN , where N is the number of radioactive atoms present. Then: $N = D(\text{dps})/\lambda(\text{sec}^{-1})$. Substituting $(\ln 2)/T$ for λ , and dividing the preceding expression by Avogadro's number (6.022×10^{23} atoms/mol) to convert atoms per liter to moles per liter (M), leads to a general equation relating radioactivity to concentration for any radionuclide:

$$M(\text{mol/l}) = 10^{-25.05} D(\text{pCi/l}) \times T(\text{sec})$$

The predominant thorium isotope (near 100% of total Th) is ^{232}Th , with a half-life of 4.4×10^{10} sec. The isotope ^{230}Th has a half-life of 2.5×10^{4} sec. Half-lives of the other thorium isotopes are given by ROSLER and LANGE (1972). The total thorium concentration based on a ^{232}Th isotope analysis is given by

$$^{232}\text{Th}(\text{mol/l}) = 10^{-7.41} D(\text{pCi/l})$$

Similarly, the molar concentration of ^{230}Th based on a ^{230}Th isotope analysis is given by

$$^{230}\text{Th}(\text{mol/l}) = 10^{-12.65} D(\text{pCi/l})$$

In order to predict the reaction chemistry of thorium it is necessary to compute total dissolved thorium from an isotopic analysis of ^{232}Th . ^{230}Th is the most important thorium isotope in the decay series beginning with ^{238}U and the most important thorium isotope in terms of its radioactivity in uranium mill tailings (ANON., 1976) and in many ground waters affected by uranium mining, milling and tailings disposal (KAUFMAN *et al.*, 1976; MOFFETT and TELLIER, 1978). The effect of reaction chemistry on ^{230}Th mobility can be estimated from its molar concentration ratio relative to ^{232}Th . Without a ^{232}Th analysis, however, the solution-reaction chemistry of ^{230}Th can only be qualitatively predicted.

MOORE and SWAMI (1972) suggest that the natural radioactivity ratio of ^{230}Th to ^{232}Th is about 0.8 in river waters and river sediments. This corresponds to a molar concentration ratio of about 4.6×10^{-6} . In ground waters, seepages and injection well waters from the uraniumiferous Grants Mineral Belt in New Mexico (KAUFMAN *et al.*, 1976) the $^{230}\text{Th}/^{232}\text{Th}$ radioactivity ratio averaged 431 and ranged from 0.96 to 1607 in 6 waters for which analyses of both isotopes were above detection. Clearly the radioactivity due to ^{230}Th usually predominates in such waters. In these same waters the concentration ratio of these isotopes averaged 2.5×10^{-3} and ranged from 0.8×10^{-3} to 9.1×10^{-3} , indicating the predominance of ^{232}Th on a concentration basis. Unfortunately, chemical and isotopic analyses of ground

waters and related hydrologic, geologic and mineralogic data are not complete enough in this or in other published studies to allow quantitative prediction of the roles of thorium complexing, solution-mineral equilibria, or thorium adsorption on thorium mobility in these natural systems.

CONCLUSIONS AND DISCUSSION

Theoretical calculations based on critically assessed thermodynamic data indicate that thorium complexing can increase the mobility of dissolved thorium by many orders of magnitude below pH 8 relative to the solubility of thorium-bearing minerals in pure water as exemplified by the solubility of thorianite (ThO_2) above pH 5, which is only 10^{-5} ppb Th as $\text{Th}(\text{OH})_4^2$. The important inorganic complexes of thorium with increasing pH are $\text{Th}(\text{SO}_4)_2^2$, ThF_3^+ , $\text{Th}(\text{HPO}_4)_2^2$, $\text{Th}(\text{HPO}_4)_3^+$ and $\text{Th}(\text{OH})_4^2$ respectively. Organic complexes as exemplified by those formed with citrate, oxalate and EDTA must greatly predominate over inorganic thorium complexes in organic-rich waters including many soil waters.

Studies by BONDIETTI (1974) and others show that adsorption of dissolved thorium increases markedly with pH above pH 2, with maximum amounts of thorium adsorption (95–100%) onto clays, oxyhydroxides and organic matter attained at pH values above 5.5–6.5. Adsorption is more complete onto humic organic solids than onto clays. Organic ligands such as citrate and EDTA that form strong thorium complexes, inhibit adsorption and can lead to partial desorption of thorium (RANCON, 1973; BONDIETTI, 1974).

Thorium is concentrated in natural sediments largely either in detrital resistate minerals such as monazite, rutile and thorianite, or adsorbed onto natural, colloidal-sized materials. The tendency of thorium to be strongly adsorbed by clays and oxyhydroxides explains its anomalously high mean concentrations in bauxites (49 ppm), bentonites (24 ppm) and pelagic clays (30 ppm), and its range in marine manganese nodules (24–124 ppm). Thorium in bauxites is apparently both sorbed and in resistate minerals. These values may be compared to thorium concentrations generally less than 13 ppm in shales, and less than 5–7 ppm in arkoses and graywackes. (Preceding data are from ROGERS and ADAMS, 1969.)

Although thorium complexing in natural waters increases the solubility of thorium-bearing minerals and can lead to desorption of thorium, thorium concentrations in natural waters (pH 5–9) rarely exceed 1 ppb. This is equivalent to a radioactivity of 0.1 pCi/l as ^{232}Th , and assuming a natural activity ratio of 0.8 for $^{230}\text{Th}/^{232}\text{Th}$ (MOORE and SWAMI, 1972) to 0.08 pCi/l as ^{230}Th . This low total thorium concentration must reflect a combination of slow solution rates, paucity and insolubility of thorium-bearing minerals, and strong adsorption of thorium by natural materials in this pH range.

Thorium adsorption and the minerals in so-called 'low a beneath an abandoned uranium Lake, Ontario, may explain ^{230}Th activities in the ground detection (MOFFETT and TELLIER, 1978). 'class' ground waters beneath ^{232}Th concentrations were (4200 pCi/l) and ^{230}Th concentration in ground water up to 0.0028 pCi/l. The thorium in the present chiefly as sulfate case of ^{232}Th by acid leaching of minerals. The U.S. Environmental Protection Agency (ANON., 1976) has reported thorium concentrations in tailings (sulfuric acid leach, Uranium Mill in 22,000 pCi/l of ^{230}Th (1.1 values reflect the greater conditions of ^{230}Th formed from ^{238}U . This may be contrasted to 110 pCi/l (0.0057 ppb) in solutions discharged from the (ANON., 1976). The alkaline the milling process tend to and the solubility of thorium ium adsorption onto clays, fine-sized materials in tailings.

The thermochemical data considered in this paper help of thorium and its isotopes, elements and wastes. However, natural systems have inevitable chemical, mineralogic, geologic data to permit an unambiguous prediction of thorium behavior. The prediction is solubility data bearing minerals such as uranotorite. Finally, more studies should be performed. Adsorption is measured as complexation, activities of their complexes, and other with an understanding of ties of the sorbent phases.

Acknowledgements—Funding portion of this research development evaluation was provided by the University of California, Berkeley, California, 45901AK, supported by the (Contract W-7405-ENG-48) Office of Nuclear Waste Isolation. Additional support through National Science Foundation AER77-06551.

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Thorium adsorption and the insolubility of thorium minerals in so-called 'low acid class' ground waters beneath an abandoned uranium tailings area at Elliot Lake, Ontario, may explain the fact that ^{232}Th and ^{230}Th activities in the ground water were below detection (MOFFETT and TELLIER, 1978). In 'high acid class' ground waters beneath the tailings, however, ^{232}Th concentrations were as high as 38 mg/l (4200 pCi/l) and ^{230}Th concentrations in the same ground water up to 0.0028 mg/l (52,000 pCi/l). Probably the thorium in these ground waters was present chiefly as sulfate complexes, released in the case of ^{232}Th by acid leaching of thorium-bearing minerals. The U.S. Environmental Protection Agency (ANON., 1976) has reported that waste milling solutions (sulfuric acid leach, pH 1.5–2) from the Highland Uranium Mill in Wyoming contained 22,000 pCi/l of ^{230}Th (1.1 ppb). These high ^{230}Th values reflect the greater mobility under acid conditions of ^{230}Th formed from the radioactive decay of ^{238}U . This may be contrasted with a ^{230}Th activity of 110 pCi/l (0.0057 ppb) in alkaline (pH = 10) leach solutions discharged from the Humeca Uranium Mill (ANON., 1976). The alkaline pH values employed in the milling process tend to minimize both complexing and the solubility of thorium minerals and favor thorium adsorption onto clays, oxyhydroxides and other fine-sized materials in tailings from the mill.

The thermochemical data and adsorption results considered in this paper help to explain the behavior of thorium and its isotopes in natural waters, sediments and wastes. However, published studies of natural systems have inevitably lacked sufficient geochemical, mineralogic, geologic and or hydrologic data to permit an unambiguous explanation for, or prediction of, thorium behavior. Also needed for such prediction is solubility data for important thorium-bearing minerals such as monazite, thorite and uranorthorite. Finally, more sophisticated adsorption studies should be performed in which thorium adsorption is measured as a function of pH, thorium complexation, activities of competing cations and their complexes, and other solution properties, and with an understanding of the detailed surface properties of the sorbent phases.

Acknowledgements—Funding of the first author for the portion of this research devoted to thermodynamic data evaluation was provided by Lawrence Berkeley Laboratories, Berkeley, California under LBL Contract No. 45901AK, supported by the U.S. Department of Energy (Contract W-7405-ENG-48) through the sponsorship of the Office of Nuclear Waste Isolation, Battelle Memorial Institute. Additional support for the project was obtained through National Science Foundation Grant No. ABR77-06651.

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REFERENCE #32

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
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T. MORRIS JUNE '90

The thermodynamic properties of radium

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Abstract—The enthalpy, Gibbs free energy, and entropies of aqueous radium species and radium solids have been evaluated from empirical data, or estimated when necessary for 25°C and 1 bar. Estimates were based on such approaches as extrapolation of the thermodynamic properties of Ca, Sr, and Ba complexes and solids plotted against cationic radii and charge to radius functions, and the use of the Fuoss or electrostatic mathematical models of ion pair formation (LANGMUIR, 1979). Resultant $\log K$ (assoc) and ΔH° (assoc) (kcal/mol) values are: for RaOH^+ 0.5 and 1.1; RaCl^+ -0.10 and 0.50; RaCO_3° 2.5 and 1.07; and RaSO_4° 2.75 and 1.3. $\log K_{sp}$ and ΔH° (dissoc) (kcal/mol) values for $\text{RaCO}_3(\text{c})$ and $\text{RaSO}_4(\text{c})$ are -8.3 and -2.8, and -10.26 and -9.4, respectively.

Trace Ra solid solution in salts of Pb and of the lighter alkaline earths, has been appraised based on published distribution coefficient (D) data, where $D \approx (mM^{2+})(N_{\text{RaX}})/(m\text{Ra}^{2+})(N_{\text{MX}})$ (m and N are the aqueous molality and mole fraction of Ra and cation M in salt X , respectively). The empirical solid solution data have been used to derive both enthalpies and Gibbs free energies of solid solution of trace Ra in sulfate and carbonate minerals up to 100°C. Results show that in every case D values decrease with increasing temperature. Among the sulfate and carbonate minerals, D values decrease for the following minerals in the order: anhydrite > celestite > anglesite > barite > aragonite > strontianite > witherite > cerussite.

INTRODUCTION

THE GEOCHEMISTRY of radium in the environment is of considerable interest because of the potential danger the element poses to human and animal health. Radium activities in excess of the U.S. ENVIRONMENTAL PROTECTION AGENCY (1977) limit of 5 pCi/l for Ra-226 plus Ra-228 in drinking water are found in ground waters from uraniferous rocks and in waters associated with uranium mining and mill tailings, and can be expected in waters that have contacted low or high level nuclear wastes.

To accurately model and predict the environmental behavior of radium in any of these situations, we need a reliable and complete thermodynamic data base for radium. Such a data base does not exist. Nearly all of the thermodynamic data for radium given by the National Bureau of Standards (WAGMAN *et al.*, 1982) has been estimated (PARKER, 1984, oral commun.). Such estimation is based on smoothly varying and known (usually) properties of the other alkaline earth aquo complexes and solids. Of all the aqueous species and solids listed by WAGMAN *et al.* (1982), only Ra^{2+} ion and $\text{RaSO}_4(\text{c})$ are likely to have any significance in the environment. On the other hand, $\text{RaCO}_3(\text{c})$ as a solid solution component, and the complexes RaOH^+ , RaCl^+ , RaCO_3° and RaSO_4° should influence radium mobility in some waters. However, no thermodynamic data are available for these entities.

THERMODYNAMIC DATA FOR PURE RADIUM SOLIDS AND AQUEOUS SPECIES

In this study, several approaches were used to estimate the thermodynamic properties of radium solids and aqueous species. The increase in cation radius of the divalent alkaline earths from Ca to Sr and Ba to Ra suggests that the bonding between these cations and common ligands should be more ionic or electrostatic for Ra than for Ba, Sr or Ca. Thus, plots of the thermodynamic properties of the alkaline earth sulfate complexes, for example, against the cation radii should approach Fuoss or electrostatic model behavior as one moves from Ca towards Ra (see LANGMUIR, 1979). The comparison is, however, best made among cations likely to have the same coordination number with a given ligand. For Ra, the coordination number is 8 or 12 in its solids (SHANNON, 1976). In a few instances, as in aragonite, Ca exists in 8-fold coordination (radius 1.12 Å); however, the best comparison is between Sr, Ba and Ra in 8-fold coordination, with effective radii of 1.26, 1.42 and 1.48, respectively (SHANNON, 1976). Examination of ΔG° and ΔS° of association of the alkaline earth sulfate complexes, plotted against charge to radius function (LANGMUIR, 1979), shows that the ΔG° data approach pure electrostatic behavior from CaSO_4° to BaSO_4° . Similar behavior is evident for ΔS° of complexation. This suggests that if the empirical ΔG° of formation of a complex can be accurately modeled with the electrostatic model, then

ΔS° of complexation can be similarly predicted. These, and other approaches used to compute or estimate the thermodynamic properties of the radium solids and aqueous species listed in Table 1, are detailed in the footnotes to the table. Shown in Table 2 are formation constants of the complexes, and solubility products of the solids listed in Table 1 and their enthalpies of reaction at 25°C.

Concentrations of radium in natural waters, and in waters associated with uranium mining and nuclear waste disposal are probably never high enough to reach saturation with a pure radium solid such as $\text{RaSO}_4(\text{c})$. Maximum Ra concentrations are limited instead by adsorption or solid solution formation. Adsorption control on aqueous Ra concentrations will be examined in detail by RIESE and LANGMUIR (in preparation). The solid solution behavior of trace Ra in major element salts has been summarized by GOLDSCHMIDT (1940) and WEIGEL (1977). In this paper we develop a comprehensive thermodynamic model with which in the absence of measured values, one can predict the solid solution behavior of Ra in divalent metal salts between 25 and 100°C.

Ra(c) and Ra^{2+} . The tabulated data are from WAGMAN *et al.* (1982). All values are estimates. A heat capacity (C_p°) of 6.86 cal/mol deg for Ra(c) may be estimated from a plot of C_p° values for Ca(c), Sr(c), Ba(c) and Ra(c) from WAGMAN *et al.* (1982) against the effective ionic radii of the divalent ions in 8-fold coordination from SHANNON (1976). A similar plot for the divalent aquo-ions with heat capacities from HELGESON *et al.* (1981) leads to $C_p^\circ(\text{Ra}^{2+}) = -12.2$ cal/mol deg.

RaOH^+ BAES and MESMER (1981) give formation constants (log K values) of 1.15 ± 0.2 , 0.71 ± 0.2 , and 0.53 ± 0.2 for CaOH^+ , SrOH^+ and BaOH^+ respectively, at 25°C. SMITH and MARTELL (1976) suggest log $K = 0.6 \pm 0.1$ for BaOH^+ at 25°C. Plotting the log K values of Baes and Mesmer against the effective ionic radii of Ca^{2+} , Sr^{2+} , Ba^{2+} and Ra^{2+} in 8-fold coordination (SHANNON, 1976), leads to log $K = 0.5$ for RaOH^+ from which ΔG° has been computed. The other thermodynamic data for RaOH^+ have been calculated assuming $\Delta H^\circ = 1.1$ kcal/mol given for BaOH^+ formation is also correct for RaOH^+ .

RaCl^+ SMITH and MARTELL (1976) give log $K = -0.13$

TABLE 1. Thermochemical data for radium solids and aqueous species, and for auxiliary aqueous species at 25°C and bar. Sources of data and methods of estimation and computation are given in the footnotes.

Solid or Aqueous Species	ΔH_f° (kcal/mol)	ΔG_f° (kcal/mol)	S° (cal/mol deg)
Ra(g)	0	0	17
Ra ²⁺	-126.1	-134.2	13
RaOH ⁺	-179.98	-172.30	16
RaCl ⁺	-165.54	-165.44	28
RaCO ₃ (c)	-286.87	-263.78	16
RaSO ₄ (c)	-342.18	-343.98	28
RaSO ₄ (c)	-352.86	-326.15	33
H ⁺	-54.977	-37.604	-2.560
Cl ⁻	-39.933	-31.379	13.56
CO ₃ ²⁻	-161.84	-126.17	-13.6
SO ₄ ²⁻	-217.40	-177.95	4.50

TABLE 2. Formation constants (log $K(\text{assoc})$ values) of radium complexes, solubility products (log K_{sp} values) of radium solids, and enthalpies of reaction (ΔH° at 25°C) based on the thermodynamic data in Table 1.

Reaction	log $K(\text{assoc})$ or log K_{sp}	ΔH° (kcal/mol)
1) $\text{Ra}^{2+} + \text{OH}^- = \text{RaOH}^+$	0.5	1.1
2) $\text{Ra}^{2+} + \text{Cl}^- = \text{RaCl}^+$	-0.10	0.50
3) $\text{Ra}^{2+} + \text{CO}_3^{2-} = \text{RaCO}_3^0$	2.5	1.07
4) $\text{RaCO}_3(\text{c}) = \text{Ra}^{2+} + \text{CO}_3^{2-}$	-8.3	-2.8
5) $\text{Ra}^{2+} + \text{SO}_4^{2-} = \text{RaSO}_4^0$	2.75	1.3
6) $\text{RaSO}_4(\text{c}) = \text{Ra}^{2+} + \text{SO}_4^{2-}$	-10.26	-9.4

at 18°C for the formation constant of BaCl^+ . Estimated with the Fuoss equation (LANGMUIR, 1979), and effective ionic radii for Ba^{2+} (8-fold) and Cl^- (6-fold), log $K = -0.10$ at 25°C. The tabulated thermodynamic properties of RaCl^+ have been similarly estimated using the Fuoss equation, supported by its applicability to BaCl^+ .

RaCO_3 . Empirical log K (assoc) values for CaCO_3 and SrCO_3 complexes are 3.20 (PLUMMER and BUSENBERG, 1982), and 2.81 (PLUMMER, 1983, oral commun.), respectively. The latter value compares with 2.82 for SrCO_3 estimated by the oxalate method (LANGMUIR, 1979). Assuming the validity of that method, we can similarly estimate log $K = 2.56$ for BaCO_3 . Linear extrapolation of the log K values for SrCO_3 from PLUMMER (1983, oral commun.) and BaCO_3 (estimated above) plotted against the effective 8-fold cation radii (SHANNON, 1976), leads to log $K = 2.5$ for RaCO_3 , from which ΔG° has been computed. Bonding of the alkaline earth carbonate complexes probably becomes more electrostatic with increasing cation size. Based on this assumption, one can compute the apparent effective radius of CO_3^{2-} in each complex with the equation log $K(\text{assoc}) = 12.44 \times 10^{-8} / (r_{\text{M}^{2+}} + r_{\text{CO}_3^{2-}})$, where the radii are in centimeters (see LANGMUIR, 1979). Resultant $r_{\text{CO}_3^{2-}}$ values increase to about 3.55×10^{-8} cm for BaCO_3 . A similar calculation for RaCO_3 assuming log $K = 2.5$ from above gives $r_{\text{CO}_3^{2-}} = 3.5 \times 10^{-8}$ cm. This suggests, as has been done, that the electrostatic model may be used to estimate S° and ΔH° for RaCO_3 .

$\text{RaCO}_3(\text{c})$. Log K_{sp} values of 9.27 ± 0.02 for SrCO_3 (BUSENBERG *et al.*, 1984), and 8.58 for BaCO_3 computed from Gibbs' free energy data given by WAGMAN *et al.* (1982) and LANGMUIR (1978), plotted against effective ionic radii of Ba^{2+} and Ra^{2+} in 8-fold coordination (SHANNON, 1976) leads to $-\log K_{sp} = 8.3$ for $\text{RaCO}_3(\text{c})$. The entropy of $\text{RaCO}_3(\text{c})$ may be estimated by Latimer's method with entropies of the ions from NAUMOV *et al.* (1974), giving 27.6 cal/mol deg. An equally valid approach is to assume $\Delta S^\circ = 0$ for the reaction: $\text{Ra(c)} + \text{BaCO}_3(\text{c}) = \text{Ba(c)} + \text{RaCO}_3(\text{c})$. With entropy data from WAGMAN *et al.* (1982), this leads to $S^\circ(\text{RaCO}_3(\text{c})) = 28.8$ cal/mol deg. The average of these two values is adopted and tabulated.

RaSO_4 . SMITH and MARTELL (1976) and MARTELL and SMITH (1982) give log K (assoc) values of 2.32, 2.55 and 2.7 for CaSO_4 , SrSO_4 and BaSO_4 . REARDON (1984, oral commun.) suggests log K (assoc) = 2.29 ± 0.02 for SrSO_4 . Examination of Fig. 11 in LANGMUIR (1979) indicates that log K (assoc) values for the alkaline earth sulfate complexes become increasingly electrostatic with cation size. The electrostatic model predicts log K (assoc) = 2.78 for BaSO_4 in good agreement with the value of Smith and Martell. The electrostatic model leads to log K (assoc) = 2.75 for RaSO_4 . A linear extrapolation of the log K (assoc) values for SrSO_4 and BaSO_4 given by SMITH and MARTELL (1976) plotted against effective cation radii from SHANNON (1976) suggests log K (assoc) = 2.76 for RaSO_4 . ΔS° (assoc) computed from the electrostatic model is 17 cal/mol deg. The tabulated data are based upon the electrostatic model.

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7	1.45
8	3.06

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RaSO₄(c). NIKITIN and TOLMATSCHIEFF (1933) have performed perhaps the most careful and thorough study of RaSO₄(c) solubility in aqueous solutions. They measured the solubility at 20°C in pure water (5 runs) and in Na₂SO₄

solutions (3 runs). Total concentrations, computed ionic strength (*I*) values, total molal concentration products ($K_{sp}' = \Sigma m_{Ra} \cdot \Sigma m_{SO_4}$), and computed thermodynamic solubility products for *I* = 0 ($-\log K_{sp}$ values) are tabulated below.

Runs	Σm_{Ra}	Σm_{Na}	Σm_{SO_4}	<i>I</i> (molal)	$-\log K_{sp}'$	$-\log K_{sp}$
1-5	6.52×10^{-6}	0	6.52×10^{-6}	2.56×10^{-5}	10.37	10.39
6	1.07×10^{-6}	1.00×10^{-4}	5.11×10^{-5}	1.54×10^{-4}	10.26	10.32
7	1.45×10^{-7}	1.00×10^{-3}	5.00×10^{-4}	1.50×10^{-3}	10.14	10.37
8	3.06×10^{-8}	1.00×10^{-2}	5.00×10^{-3}	1.50×10^{-2}	9.82	10.56

The $-\log K_{sp}$ value from run 8 is entirely inconsistent with the other values, and is therefore rejected. The average of the results for runs 1-7 is 10.38 ± 0.02 , where the uncertainty is twice the standard deviation of the mean. The following assumptions were made in order to calculate $-\log K_{sp}$ values in the above table:

a) $\log K'$ (assoc) (RaSO₄) = 2.74 at 20°C. This is based on the 25°C value of 2.76, corrected to 20° using the van't Hoff equation and enthalpy data from Table 1.

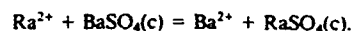
b) $\log K'$ (assoc) (NaSO₄) = 0.81 at 20°C. This is based on a 25°C value of 0.82 (REARDON, 1975), ΔH° (assoc) = 1.1 kcal/mol at 25°C (SMITH and MARTELL, 1976), and the van't Hoff equation. This species is negligible in all but run 8.

c) Activity coefficients may be computed using the Debye-Hückel equation, assuming $\gamma_{Ra^{2+}} = \gamma_{Ba^{2+}}$, and $\gamma_{NaSO_4} = \gamma_{NaCl}$; and the equation $\log \gamma_{RaSO_4} = 0.5I$ (REARDON and LANGMUIR, 1976). Our selected $-\log K_{sp}$ value of 10.38 ± 0.02 may be compared with 10.37 given by SMITH and MARTELL (1976) also for 20°C and based on the work of Nikitin and Tolmatscheff (*ibid*).

Data given by WAGMAN *et al.* (1982) leads to ΔH° (assoc) = 0.55 kcal/mol for celestite. BLOUNT (1977) suggests ΔH° (assoc) = -6.35 kcal/mol for barite. A linear plot of these values against the effective ionic radii of the cations in 8-fold coordination (SHANNON, 1976) extrapolates to ΔH° (assoc) = -9.3 kcal/mol for RaSO₄(c). Substituted into the van't Hoff equation, this latter value leads to $-\log K_{sp} = 10.26 \pm 0.02$ at 25°C for RaSO₄(c). Based on this constant and the enthalpy of association, and with entropy data from Table 1, $S^\circ = 33.3$ cal/mol deg for RaSO₄(c). S° (RaSO₄(c)) may be estimated independently using Latimer's method with entropy data from NAUMOV *et al.* (1974), which leads to $S^\circ = 32.0$ cal/mol deg. A second estimate, made with entropy data from WAGMAN *et al.* (1982), and based on the assumption that $\Delta S^\circ = 0$ for the reaction $Ra(c) + BaSO_4(c) = Ba(c) + RaSO_4(c)$, gives 33.6 cal/mol deg. The excellent agreement among these three entropy values supports the empirical and estimated $-\log K_{sp}$ and ΔH° (assoc) values for RaSO₄(c). An entropy of 33 cal/mol deg, the same as chosen by WAGMAN *et al.* (1982), is adopted and tabulated. ΔH_f° for the solid is computed assuming this entropy and $-\log K_{sp} = 10.26$.

LIND *et al.* (1918) measured the solubility of RaSO₄(c) in 0.01 N H₂SO₄ solutions at 25 and 35°C, and obtained 2×10^{-4} g/l and 3×10^{-4} g/l, respectively. This solubility increase with temperature corresponds to an increase in $-\log K_{sp}$ of 0.18 units between 25 and 35°C. Using the van't Hoff equation and the ΔH° value for RaSO₄(c) dissolution given in Table 2, we may compute a $-\log K_{sp}$ increase of 0.22 units for this same temperature interval, in good agreement with the results of Lind and others.

A fairly accurate determination of the effect of temperature on the solubility of RaSO₄(c) above 25°C may be made by assuming that the heat capacity is zero at all temperatures for the reaction



With enthalpy and free energy data from this paper and from LANGMUIR and MELCHIOR (1985) we compute $\Delta G^\circ = -396$ cal/mol, $\Delta H^\circ = -3050$ cal/mol, and thus $\Delta S^\circ = 8.9$ cal/mol deg. Assuming $\Delta C_p^\circ = 0$ for this reaction, and introducing the temperature function for $\log K_{sp}$ (barite) at 1 bar from LANGMUIR and MELCHIOR (1985) (see also BLOUNT, 1977), leads to

$$\log K_{sp} (RaSO_4) = 137.98 - 8346.87/T - 48.595 \log T$$

where *T* is in kelvins. The effect of pressure on $\log K_{sp}$ (RaSO₄) may be assumed equal to that effect for barite (LANGMUIR and MELCHIOR, 1985).

OH⁻ and Cl⁻: CODATA (1976)

CO₃²⁻: WAGMAN *et al.* (1982)

SO₄²⁻: CODATA (1977).

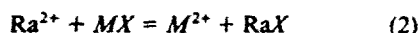
SOLID SOLUTION FORMATION

The tendency for trace radium concentrations to coprecipitate and form a solid solution with barite is well known (*cf.* DOERNER and HOSKINS, 1925; and CHURCH, 1979), and is the basis for radium removal from mine waters and acid sulfate and uranium mill tailings solutions or raffinates by the addition of soluble barium salts (*cf.* SEBESTA *et al.*, 1981). Less well known is the solid solution behavior of trace Ra concentrations in other minerals, or the importance of Ra solid solutions generally as controls on Ra in natural waters. Published data on radium solid solutions in which Ra is the trace component are given for Ra-BaSO₄ by DOERNER and HOSKINS (1925), and for numerous other solid solutions by GOLDSCHMIDT (1940) and WEIGEL (1977). Much of the data has been cast in terms of an empirically determined distribution coefficient, *D*, where

$$\frac{m_{Ra^{2+}}}{m_{M^{2+}}} \cdot D = \frac{N_{Ra}}{N_M} \quad (1)$$

for the ratio of molal aqueous concentrations of radium to the major ion *M*, equals the corresponding ratio of their mole fractions in the solid solution. This expression is called the "Nernst-Berthelot equation" (WEIGEL, 1977), or "Henderson-Kraczek equation" (O'NIONS and POWELL, 1977), and applies to solid solution formation from an aqueous solution of constant composition, or in other words, to the formation of a compositionally homo-

geneous solid solution. (Crystallization of a zoned solid solution from an aqueous solution of changing composition (usually in a closed system) is described by the equation of DOERNER and HOSKINS (1925); see also RAISWELL and BRIMBLECOMBE (1977), and WEIGEL (1977)). The exchange reaction for a solid solution involving trace Ra and a major carrier or host divalent metal salt, may be written



for which

$$K_{\text{ex}} = \frac{\gamma_{\text{M}^{2+}} m_{\text{M}^{2+}} \cdot \lambda_{\text{RaX}} N_{\text{RaX}}}{\gamma_{\text{Ra}^{2+}} m_{\text{Ra}^{2+}} \cdot \lambda_{\text{MX}} N_{\text{MX}}} \quad (3)$$

where the γ and m terms are the ion activity coefficients and molal concentrations in aqueous solution, and the λ and N terms the rational activity coefficients and mole fractions in the solid solution. We can compute K_{ex} directly from Gibbs free energy data for the reaction through

$$\Delta G_{\text{ex}}^0 = -RT \ln K_{\text{ex}} \quad (4)$$

or from the fact that $K_{\text{ex}} = K_{\text{sp}}(\text{MX})/K_{\text{sp}}(\text{RaX})$.

Inspection of expressions (1) and (3) leads to the statement

$$K_{\text{ex}} = D \cdot \frac{\gamma_{\text{M}} \lambda_{\text{RaX}}}{\gamma_{\text{Ra}} \lambda_{\text{MX}}} \quad (5)$$

In every case considered in this study, M is a divalent cation, and in dilute solutions we may generally assume $\gamma_{\text{M}^{2+}} = \gamma_{\text{Ra}^{2+}}$. Also, in every case we are considering a solid solution in which RaX is a trace component in MX , so that $\lambda_{\text{MX}} \approx N_{\text{MX}} \approx 1$. Accordingly, the expression for K_{ex} may be simplified to

$$K_{\text{ex}} = D \cdot \lambda_{\text{RaX}} \quad (6)$$

Because the activity of RaX in the solid solution is $d_{\text{RaX}} = \lambda_{\text{RaX}} \cdot N_{\text{RaX}}$, but also $d_{\text{RaX}} = K_H \cdot N_{\text{RaX}}$, where K_H is the Henry Law constant, then also $\lambda_{\text{RaX}} = K_H$. Multiplying $-RT$ times the natural log of expression (6) leads to

$$\Delta G_{\text{ex}}^0 = -RT \ln K_{\text{ex}}$$

$$= -RT \ln D - RT \ln \lambda_{\text{RaX}} \quad (7)$$

The first and second terms on the right may be designated $\Delta G_{\text{ex}}^0(D)$ and $\Delta G_{\text{ex}}^0(\lambda)$ so that

$$\Delta G_{\text{ex}}^0 = \Delta G_{\text{ex}}^0(D) + \Delta G_{\text{ex}}^0(\lambda) \quad (8)$$

If empirical data for the temperature variation of D are available, and if a plot of $\log D$ versus $1/T$ yields a straight line, then through the integrated van't Hoff equation we find

$$\Delta H_{\text{ex}}^0(D) \text{ cal/mol} = 4.576 \left[\log \left(\frac{D_2}{D_1} \right) \right] \left(\frac{T_2 T_1}{T_2 - T_1} \right) \quad (9)$$

By analogy to the treatment of Gibbs free energy

$$\Delta H_{\text{ex}}^0 = \Delta H_{\text{ex}}^0(D) + \Delta H_{\text{ex}}^0(\lambda) \quad (10)$$

where ΔH_{ex}^0 is the standard enthalpy of the exchange reaction, and $\Delta H_{\text{ex}}^0(\lambda)$ the enthalpy contribution due

to non-ideality of the solid solution. It can readily be shown that

$$\Delta H_{\text{ex}}^0(\lambda) \text{ cal/mol} = 4.576 \left[\log \left(\frac{\lambda_{\text{RaX}(2)}}{\lambda_{\text{RaX}(1)}} \right) \right] \left(\frac{T_2 T_1}{T_2 - T_1} \right) \quad (11)$$

or stated differently

$$\log \lambda_{\text{RaX}(2)} = \log \lambda_{\text{RaX}(1)} - \frac{\Delta H_{\text{ex}}^0(\lambda)}{4.576} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \quad (12)$$

Plotted in Fig. 1 are $\Delta G_{\text{ex}}^0(D)$ values against ΔG_{ex}^0 values for 14 trace Ra-major divalent ion salts. The D values used to compute $\Delta G_{\text{ex}}^0(D)$ are from DOERNER and HOSKINS (1925), GOLDSCHMIDT (1940), and WEIGEL (1977). The ΔG_{ex}^0 values have been computed using free energy data from Table 1, WAGMAN *et al.* (1982), and LANGMUIR (unpub. data). The plot shows a strong correlation between the two variables, with increased selectivity of host salts for Ra exhibited as ΔG_{ex}^0 becomes more negative. Obviously, for D values greater than unity, ($\Delta G_{\text{ex}}^0(D) < 0$), Ra is favored over the major cation in the solid solution, and conversely for D values less than unity ($\Delta G_{\text{ex}}^0(D) > 0$). Figure 1 shows a strong correlation ($r^2 = 0.95$), with the equation of the line equal to

$$\Delta G_{\text{ex}}^0(D) = 0.492 \Delta G_{\text{ex}}^0 \quad (13)$$

The effect of temperature on D values, based chiefly on data from GOLDSCHMIDT (1940), is plotted in Fig. 2. The figure shows that D values decrease with increasing temperature, consistent except for $\text{Ba}(\text{C}_2\text{H}_3\text{O}_2)_2$ and $\text{Sr}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, with a decreasing selectivity difference between the ions at higher temperatures. The plot also shows that D varies linearly or nearly so with $1/T$. This indicates that in most cases $\Delta H_{\text{ex}}^0(D)$ for the exchange reaction is constant from 0 to 100°C. $\Delta H_{\text{ex}}^0(D)$ values for the nine solid solutions based on Fig. 2 and the van't Hoff equation, are listed in Table 3, along with other thermodynamic properties of the solid solutions at 25°C, computed

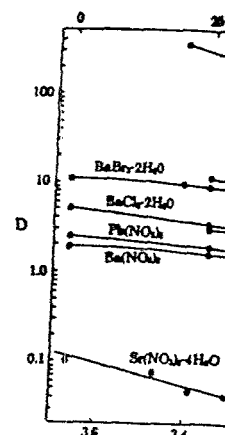


FIG. 2. Empirical dis trace radium solid soluti salts as a function of ten

as described above. A for the six solid soluti The equation of the li

$$\Delta H_{\text{ex}}^0(I$$

($r^2 = 0.91$). Equations to estimate missing the and 4.

Of particular interestibilities of trace Ra in carbonate minerals as a effect of increasing term between 0 and 100°C decrease in D and λ_1 corresponds to a major, host minerals for trace trace Ra is more selecti anglesite than in barite.

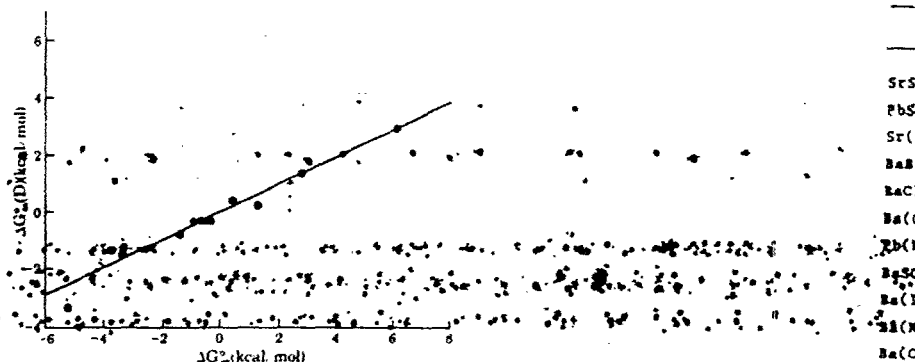


FIG. 1. Plot of $\Delta G_{\text{ex}}^0(D)$ versus ΔG_{ex}^0 for trace radium solid solution in some major divalent metal salts at 25°C. The line through the data is constrained to pass through the point $\Delta G_{\text{ex}}^0(D) = \Delta G_{\text{ex}}^0 = 0$.

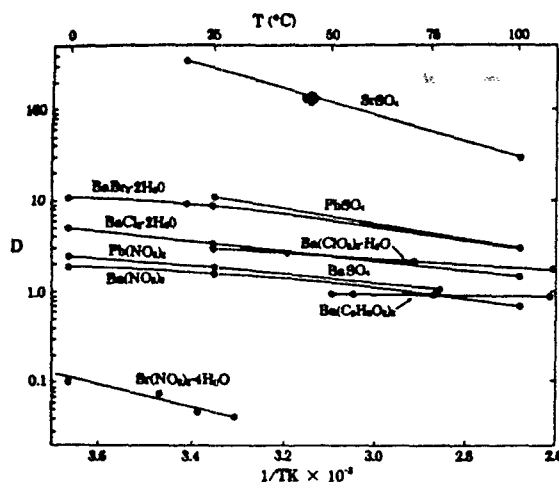


FIG. 2. Empirical distribution coefficient (D) values for trace radium solid solution in some major divalent metal salts as a function of temperature.

as described above. A plot of $\Delta H_{ex}^0(D)$ versus ΔH_{ex}^0 for the six solid solutions in Fig. 2 is given in Fig. 3. The equation of the line through the data is

$$\Delta H_{ex}^0(D) = 0.642\Delta H_{ex}^0 \quad (14)$$

($r^2 = 0.91$). Equations (13) and (14) have been used to estimate missing thermodynamic data in Tables 3 and 4.

Of particular interest geochemically are the solubilities of trace Ra in Ca, Sr, Ba and Pb sulfate and carbonate minerals as a function of temperature. The effect of increasing temperature on D and λ_{RaX} values between 0 and 100°C is shown in Table 4. The decrease in D and λ_{RaX} values with temperature corresponds to a major reduction in the selectivity of host minerals for trace Ra. Somewhat surprisingly, trace Ra is more selectively enriched in celestite and anglesite than in barite. None of the carbonate min-

erals prefer Ra over their major cations. Also, the table shows that λ_{RaSO_4} and λ_{RaCO_3} in barite and witherite, respectively, are near unity at 25°C, and so these Ra-Ba salts behave as ideal solutions.

The solubility of trace Ra in rock-forming minerals such as gypsum, anhydrite, calcite and dolomite is either not known or only approximately known. If one assumes that Ra solubility in anhydrite follows the same general relations already described for Ra solubility in other salts, then from Eqn. (13) we can compute $D = 800$ at 25°C. Examination of D values given by GOLDSCHMIDT (1940) shows that in every case D is greater for the anhydrous salt than hydrous salt at the same temperature. If $D = 800$ for anhydrite is correct, then D for gypsum should be less than this, although how much is uncertain. GOLDSCHMIDT (1940) measured an approximate selectivity of gypsum for Ra at 25°C and obtained $D \approx 0.02$. The model-predicted D value for anhydrite is larger than any measured D value in Table 3. However, the trend in D values for the sulfates with radius of the host cation is clear from the data. Thus, in the sequence of decreasing cation radius from Ra to Ba, Pb and Sr, corresponding D values increase from 1.0 to 1.8, 11 and 280. This trend indicates an increase in the solubility of Ra in host sulfate minerals with an increase in the difference between the ionic radii of Ra and the host cation. The same behavior is apparent for the carbonate solid solutions, although the magnitude of the effect is far less pronounced than for the sulfates. Such behavior is clearly at variance with conventional wisdom regarding the effect of ionic radii differences between cations on their binary solid solution behavior.

Considered from a thermodynamic point of view, however, there is logic to the trends. Among the alkaline earth sulfates, $RaSO_4$ has a K_{sp} of -10.26 , followed by K_{sp} values of -9.97 , -6.64 and -4.36 for $BaSO_4$, $SrSO_4$, and $CaSO_4$ (LANGMUIR and MEL-

TABLE 3. Thermodynamic properties of trace Ra-major salt solid solution. ΔH_{ex}^0 and ΔG_{ex}^0 are in kcal/mole. $\Delta H_{ex}^0(D)$ and $\Delta G_{ex}^0(D)$ are in kcal/mole. D and λ_{RaX} are dimensionless. Parentheses enclose values estimated from equations (13) or (14), or derived from such estimates.

	ΔH_{ex}^0	$\Delta H_{ex}^0(D)$	ΔG_{ex}^0	$\Delta G_{ex}^0(D)$	D	λ_{RaX}
$SrSO_4$ (celestite)	-9.93	-6.58	-5.16	-3.34	280	215
$PbSO_4$ (anglesite)	-7.25	-3.83	-3.37	-1.42	11	26.8
$Sr(NO_3)_2$	-7.55	(-4.85)	-3.36	-1.36	10	29.0
$BaBr_2 \cdot 2H_2O$	-5.9	-3.24	-3.60	-1.30	9	37.9
$BaCl_2 \cdot 2H_2O$	-3.43	-2.50	-1.36	-.74	3.5	2.17
$Ba(ClO_3)_2 \cdot H_2O$	(-2.35)	-1.51	(-1.36)	-.67	3.1	(3.2)
$Pb(NO_3)_2$	-3.3	-1.51	-.96	-.38	1.9	2.66
$BaSO_4$ (barite)	-3.2	-2.03	-.41	-.35	1.8	1.11
$Ba(IO_3)_2$	-2.3	(-1.48)	-.72	-.31	1.7	1.98
$Ba(NO_3)_2$	-2.9	-2.44	-.30	-.28	1.6	1.86
$Ba(C_2H_3O_2)_2$	(-.50)	-.32	(.05)	.024	.96	(1.13)
$SrCO_3$ (strontianite)	-3.81	(-2.45)	1.3	.25	.66	.17
$BaCO_3$ (witherrite)	-2.43	(-1.56)	.39	.41	.5	1.04
$Sr(NO_3)_2 \cdot 4H_2O$	(-5.08)	-5.19	2.80	1.36	.1	.089
$PbCO_3$	-6.8	(-9.50)	6.14	2.98	.067	.00047

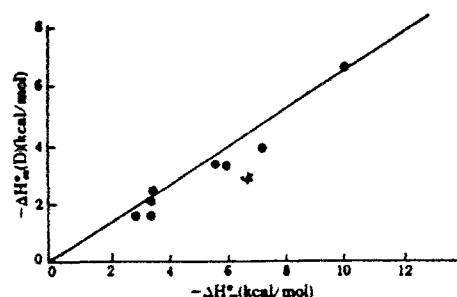


FIG. 3. Plot of $\Delta H_m^0(D)$ versus ΔH_m^0 for trace radium solid solution in some major divalent metal salts at 25°C. The line through the data is constrained to pass through the point $\Delta H_m^0(D) = \Delta H_m^0 = 0$.

CHIOR, 1985). RaSO_4 is obviously the *least* soluble sulfate; nearly six orders of magnitude less so than anhydrite. The stability constants indicate that bonding between Ra and SO_4 is much stronger, than between Ca and SO_4 . One could then argue that given competition between the cations in a sulfate lattice, Ra would be favored over Ca. This effect should increase as the difference in stability constants between Ra and the host cation increases.

Among the alkaline earth carbonates, however, RaCO_3 is the *most* soluble, with $K_{sp} = -8.3$, followed by aragonite, calcite, witherite and strontianite, with K_{sp} values of -8.34 , 8.48 , (PLUMMER and BUSENBERG, 1982), and -8.58 , and -9.27 (see footnote $\text{RaCO}_3(c)$ and Table 1). In this case the trend in D values is opposite, probably for the same reason as given for the sulfates. Model-predicted D values for calcite and aragonite are 0.82 and 0.96, respectively. $D = 0.5$ for witherite indicates further exclusion of Ra, as the host carbonate becomes even more insoluble than RaCO_3 . $D = 0.66$ for strontianite is inconsistent with the trend in D with K_{sp} , but probably within the uncertainties in the D values.

These observations suggest that at trace concentrations of Ra, the solid solution behavior of the sulfates and carbonates is more dependent on the thermodynamic properties of the Ra and host cation salts, than on differences in the cationic radii. The D values obtained by GOLDSCHMIDT (1940) were measured at N_{RaX} values between 10^{-5} and 10^{-11} . Radium concentrations in natural waters rarely exceed 10^{-12} M (cf. LANGMUIR and MELCHIOR, 1985). Combined with concentration data for Ca, Sr, Ba, and Pb, and using Eqn. (1), it seems unlikely that N_{RaX} will exceed 10^{-5} in natural water/rock systems. At such low N_{RaX} concentrations, crystal strain caused by Ra substitution is probably negligible. Under these conditions, simple thermodynamic principles apparently control solid solution behavior.

For a trace Ra solid solution to play an important role in Ra ground water transport, the host mineral must be close to saturation with respect to the water. That this condition exists can be

by inputting the ground water chemical analysis into a computer program such as WATEQF (PLUMMER *et al.*, 1976) for ionic strengths less than about 0.1 molal, or for higher ionic strengths into a computer program for calculation of ion activities via the ion-interaction approach of Pitzer (cf. HARVIE and WEARE, 1980; LANGMUIR and MELCHIOR, 1985). Once saturation with respect to a host mineral is proven, then

$$N_{\text{RaX}} = D_{\text{RaX}} \cdot \frac{[\text{Ra}^{2+}]}{[M^{2+}]} \quad (15)$$

so that N_{RaX} in the host mineral may be computed from the ion activity ratio in the water. Note that the ion activity ratio has been substituted for the molal ratio in Eqn. (15). Most empirical D values have been measured in sufficiently dilute solutions so that these ratios are roughly equal. [At high ionic strengths in strongly complexing solutions they may not be, so that to be rigorous, we will henceforth deal with the activity ratio only.]

To determine the relative importance of trace Ra solid solutions, we not only must know the thermodynamic properties of these solutions, but also their abundances in water-rock systems. If the rock is composed of several host minerals of divalent cations, then the total Ra in solid solution in a given rock mass is

$$\text{Ra } (\mu\text{g/g rock}) = 226 \sum D_{\text{RaX}} \times \left(\frac{[\text{Ra}^{2+}]}{[M^{2+}]} \frac{\text{Wt MX } (\mu\text{g/g rock})}{(\text{GFW MX } (\text{g/mol}))} \right) \quad (16)$$

As Eqn. (16) indicates, for a given Ra concentration the importance of a particular solid solution as a Ra sink is directly proportional to the abundance of the host mineral and the value of D , and inversely proportional to the activity of M^{2+} in solution. Unfortunately, there are no published data that allow us to test this equation. AMES and RAJ (1978) tabulate the Ra content of several major rock types, and suggest that the average Ra content of limestone is 0.42×10^{-6} $\mu\text{g/g rock}$. With Eqn. (16) we may estimate $\text{Ra} = 0.054 \times 10^{-6}$ $\mu\text{g/g rock}$ in fresh marine limestone. That this value is less than measured probably reflects that the Ra in limestone is almost entirely Ra-226 formed by the decay of U-238 already

TABLE 4. Distribution coefficients and rational activity coefficients for trace Ra in some sulfate and carbonate minerals at 0 and 100°C. Values in parentheses are estimates. See text.

Mineral	D(25°C)	D(100°C)	$\lambda(25^\circ\text{C})$	$\lambda(100^\circ\text{C})$
CaSO_4 (anhydrite)	(800)	(40)	(29.8)	(5.6)
SrSO_4 (celestite)	280	30	215	69
PbSO_4 (anglesite)	11	3	26.8	8.4
BaSO_4 (barite)	1.8	.90	1.11	.75
CaCO_3 (aragonite)	(.96)	(.95)	(3.09)	(1.84)
CaCO_3 (calcite)	(.82)	(.77)	(.81)	(.79)
SrCO_3 (strontianite)	.66	(.29)	.17	(.11)
BaCO_3 (witherite)	.5	(.29)	1.04	(.77)
PbCO_3 (cerussite)	.067	(.027)	.00047	(.000077)

present in rocks is 2 (1982). Eq. of a horn from a wa icant radi bration. S some inst uncharact ural hydr Ra-226 is

CHURC of modern constant $\times 10^{-4}$ μg 228/Ra-226 takes plac such barit in-barite value of 0 the water less than this paper

A second the relative listed in mineral is of the ro percents o given in may be s probably c 1% level, important magnitude amount t anglesite c level.

Ra

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TABLE 5. of minerals

Host Min

anhydrite
limestone
(calcite)
celestite
barite
anglesite

Ra = 226

Assuming
tion or

present in the limestone. (The average U in carbonate rocks is 2.2 $\mu\text{g/g}$, according to MASON and MOORE, 1982). Equation (16) only applies to the formation of a homogeneous solid solution incorporating Ra from a water of constant composition without significant radioactive decay, or with continuous reequilibration. Such conditions are probably approached in some instances of nuclear waste disposal, but may be uncharacteristic of radium geochemistry in most natural hydrogeologic environments. (The half-life of Ra-226 is 1622 years).

CHURCH (1979) notes that the Ra-226/Ba content of modern marine barites and pore waters is practically constant with depth in some Pacific cores at $2.4 \times 10^{-4} \mu\text{g/g}$. This fact, and a relatively constant Ra-228/Ra-226 ratio in these barites indicates that radium-barium exchange between the water and barite takes place within a few years. This suggests that such barites are rapidly forming a homogeneous Ra-in-barite solid solution. However, the empirical D value of 0.18 derived from analyses of Ra and Ba in the water and barite is inexplicably about ten times less than theoretically predicted for 3°C , based on this paper.

A second calculation provides further insight into the relative importance of the Ra-solid solutions listed in Tables 3 and 4. Assuming that each host mineral is at saturation with seawater, the Ra content of the rock has been computed assuming weight percents of the host minerals present. The results are given in Table 5. Anhydrite (and possibly gypsum) may be significant sinks for Ra. Limestone (and probably dolomite) are unimportant; however, at the 1% level, barite, and especially anglesite are more important than the carbonates by about six orders of magnitude. At 0.03 wt% of the rock, too small an amount to be identified by conventional means, anglesite can hold as much Ra as barite at the 1% level.

RADIOACTIVITY-CONCENTRATION RELATIONSHIPS

Radium analyses are generally reported in terms of the radioactivity of a particular Ra isotope, whereas

such reactions as adsorption, precipitation, and complexation are written in terms of molar or molal concentrations. Radium isotope concentrations in water are usually given in picoCuries (1 pCi = 10^{-12} Ci) or decays per second (1 pCi = 0.037 dps). The general expression relating decay (d) rate to molar concentration (M) is

$$M (\text{Mol/l}) = 10^{-25.05} \cdot d (\text{pCi/l}) \times T (\text{sec}) \quad (17)$$

where T is the half-life of the isotope in seconds (LANGMUIR and HERMAN, 1980). The important isotopes of Ra and their half-lives are listed below (AMES and RAI, 1978).

Isotope	Half life	Series
Ra-223	11.43 d	U-235
Ra-224	3.64 d	Th-232
Ra-226	1622 y	U-238
Ra-228	5.77 y	Th-232

In the case of Ra-226, the conversion factor from pCi/l to picograms per liter is unity. The corresponding conversion from pCi/l to M (Mol/l) is

$$\text{Mol/l (Ra-226)} = 10^{-14.34} \cdot d (\text{pCi/l}). \quad (18)$$

The short-lived isotopes Ra-223 and Ra-224 are unlikely to be significantly involved in solution-mineral equilibria, which have low-temperature reaction rates most often in weeks to years. However, all the Ra isotopes must participate in complexation and adsorption-desorption reactions. The latter go to completion within seconds to a few hours unless diffusion controlled.

Another point, rarely considered, is that the extent of reaction of a particular radionuclide in a geochemical process such as adsorption or precipitation, is proportional to the ratio of the isotope's molar concentration to the total concentration of the element. This fact is irrelevant to the geochemistry of Ra-226, the predominant isotope, which greatly exceeds 99% of total Ra, but must be considered in reactions involving the other Ra isotopes.

Rigorous application of the thermodynamic data presented in this paper to radium behavior in water-rock systems requires that we have rock chemical and isotopic data, as well as measured concentrations of Ra and related aqueous species in the water. Such rock data is practically nonexistent. Numerous recent papers have reported Ra concentrations in surface and ground waters. Introducing the thermodynamic properties of radium into aqueous-reaction computer codes such as WATEQF (PLUMMER *et al.*, 1976) allows us to determine the reaction state of a water with respect to radium. Application of such an approach to the published literature on Ra in ground water will be presented in a following paper.

TABLE 5. Hypothetical Ra contents of some rocks composed of minerals assumed at equilibrium with sea water at 25°C .

Host Mineral	Wt% of host mineral in the rock	Molal concentration of host mineral cation in sea water ^a	Ra ($\mu\text{g/g}$) in rock ^b
anhydrite	100	1.03×10^{-2}	39×10^{-6}
limestone (calcite)	100	1.03×10^{-2}	$< 0.054 \times 10^{-6}$
celestite	1	9.1×10^{-5}	11×10^{-6}
barite	1	1.5×10^{-5}	3500×10^{-6}
anglesite	1	2×10^{-10}	$123,000 \times 10^{-6}$

^a $\text{Ra} = 3 \times 10^{-16} \text{M}$. Concentrations from Henderson (1982).

^bAssuming a homogeneous solid solution, and no net depletion or addition of Ra-226 after solid solution formation.

CONCLUSIONS AND DISCUSSION

We have critically appraised the available thermodynamic data for aqueous radium species, pure solids and solid solutions of geochemical importance, and presented an internally consistent tabulation of preferred thermodynamic values. These have been estimated for the aqueous species, and derived from empirical data or estimated for pure Ra solids and solid solutions. A model has been developed that permits prediction of the extent of trace Ra solid solution and its temperature variation, given only the standard state Gibbs free energies and enthalpies of the ions and the pure Ra and host divalent salts at 25°C and 1 bar.

Although empirical data support the solid solution model, there is a lack of experimental measurements of radium solid solution in major rock-forming sulfate and carbonate minerals, for example, with which to test the model. There is also a need for data on the Ra content of major and minor rock-forming minerals, including studies of the Ra distribution (zoning, etc.) in such minerals. When possible and appropriate, the mineralogical data should be obtained along with Ra and other isotopic and chemical analytical data for coexisting waters. The extent of such information already published will be examined by RIESE and LANGMUIR (in preparation).

Acknowledgements—The first author's funding was obtained from the U.S. Department of Energy, through the Office of Nuclear Waste isolation, Battelle Project Management Division, Columbus, OH, through BPMD Contract E512-09500, Dr. Norman Hubbard, Project Manager. A. C. Riese was supported by Atlantic Richfield Company and Gulf Research and Development Company.

Editorial handling: R. A. Schmitt

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Geochemistry of selenium: formation of ferroselite and selenium behavior in the vicinity of oxidizing sulfide and uranium deposits

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(Received 19 September 1975; accepted in revised form 18 July 1977)

Abstract—The geochemistry of Se is largely controlled by that of iron, with which Se is closely affiliated in both oxidizing and reducing environments. In aerated waters the Se(IV) oxyanions, HSeO_3^- and SeO_3^{2-} are strongly adsorbed by hydrated surfaces of ferric oxides over the pH range 2–8; above pH 8 adsorption decreases to complete desorption at pH 11. This adsorption immobilizes Se(IV) in neutral-to-acid waters and increases the range of oxidation potential over which Se(IV) is stable. During experimental aeration of aqueous Fe–S–Se systems, the stability field of Se(IV) is attained, and elemental Se is slowly oxidized to this higher valence; oxidation potentials of the Se(VI) stability field were never reached, however, even by continued aeration of an alkaline system. Under reducing conditions, elemental Se either is incorporated within pyrite or forms the mineral ferroselite (FeSe_2).

Selenium geochemistry is summarized on an Eh–pH diagram, synthesized from equilibrium calculations, experimental work, and reported geologic occurrences. A stability field for ferroselite, constructed for a Gibbs free-energy value of -23.2 kcal/mole, is in accord both with its geologic occurrence and behavior and with conditions under which ferroselite has been synthesized. Traces on this diagram of Eh–pH variation show the behavior of selenium during oxidation of associated iron-sulfide minerals. Such considerations also demonstrate the manner in which selenium migrates, is deposited, and is increasingly concentrated in roll-type sandstone uranium deposits, as well as the relative positions of the several forms of selenium within the deposit.

INTRODUCTION

SINCE the studies of selenium by GOLDSCHMIDT and his coworkers (1933, 1935) and the almost coincident discovery that acute and chronic livestock poisoning in the western Great Plains of the United States was caused by selenium assimilated by forage crops from the soil [see ROSENFELD and BEATH (1964) for historical summary], there has been continual study of the geologic occurrence and geochemistry of selenium. Important works include summary books (TRELEASE and BEATH, 1949; ANDERSON *et al.*, 1961; ROSENFELD and BEATH, 1964; SINDEEVA, 1964; MUTH, 1967; LEUTWEIN, 1972), annotated bibliographies (LUTTRELL, 1959; GENT, 1976), and detailed geochemical studies (LAKIN and TRITES, 1956; COLEMAN and DELEVAUX, 1957; DAVIDSON and POWERS, 1959; DAVIDSON, 1960, 1963; TISCHENDORF and UNGETHÜM, 1964; D'YACHKOVA, 1965; D'YACHKOVA and KHODAKOVSKIY, 1968; GEERING *et al.*, 1968; HINGSTON *et al.*, 1968; WARREN, 1968; BUR'YANOVA, 1969).

At the surface of the Earth selenium occurs in diagenetic pyrite of fine-grained sediments (HOWARD, 1969)—for example, certain Upper Cretaceous formations of the western interior United States—and, in oxygenated aqueous environments, with hydrous iron oxides (GOLDSCHMIDT and STROCK, 1935; LAKIN and DAVIDSON, 1967; HOWARD, 1972). Incorporation of selenium into sulfides is due to the similarity in chemical properties of elemental selenium to sulfur and of ionic selenide to sulfide (GOLDSCHMIDT and

HEFTER, 1933); its association with hydrous iron oxides is accomplished through strong adsorption of the selenite ions (HSeO_3^- and SeO_3^{2-}) upon the hydroxylated surfaces of the iron oxides (PLOTNIKOV, 1964; HINGSTON *et al.*, 1968; HOWARD, 1972). Pyrite and hydrous iron oxides are abundant and ubiquitous, and these minerals are thus important in controlling the geochemical behavior and occurrence of selenium both in reducing environments and in more oxidizing milieux.

Selenium is concentrated also in high-temperature sulfide ore deposits and in uranium deposits in sandstones (COLEMAN and DELEVAUX, 1957; DAVIDSON, 1960, 1963; GOLDSCHMIDT and HEFTNER, 1933; LAKIN and DAVIDSON, 1967; ROSENFELD and BEATH, 1964; SINDEEVA, 1964; FARAMAZYAN and ZAR'YAN, 1964; CHITAYEVA, 1965; D'YACHKOVA and KODAKOVSKIY, 1968; BUR'YANOVA, 1969). The selenium of these deposits is contained within the sulfide minerals and is also common as native selenium and the selenide minerals: ferroselite (FeSe_2), clausthalite (PbSe), stibnite (Sb_2Se_3), cadmoselite (CdSe), berzelianite (Cu_2Se), eucairite (AgCuSe), and others (see BUR'YANOVA, 1969; SINDEEVA, 1964; TISCHENDORF and UNGETHÜM, 1964).

GOLDSCHMIDT and his coworkers (1933, 1935) interpreted the selenium cycle on the basis of the known chemistry of that element, analyses of many different types of geologic materials, and a few chemical experiments with selenium and iron hydroxide. Their con-

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clusions were essentially the following: (1) in magmatic activity selenium is incorporated in sulfide minerals or in volcanic sulfur; (2) selenium is separated from sulfur during weathering by oxidation to elemental selenium or to the selenite ion, SeO_3^{2-} , while sulfur is oxidized to a soluble, mobile SO_4^{2-} ion; (3) of the sedimentary rocks, shales and particularly iron and manganese ores are enriched in selenium; and (4) the SeO_3^{2-} is coprecipitated or strongly adsorbed by freshly precipitated ferric hydroxide, thus explaining its enrichment in sedimentary iron-oxide beds. Subsequent interpretations of selenium geochemistry are based upon the selenium content of various types of geologic materials and are generally similar to those of Goldschmidt, with elaboration and refinement made possible with the accrual of analytical data (BYERS *et al.*, 1938; LAKIN, 1961; LAKIN and DAVIDSON, 1967; ROSENFELD and BLATH, 1964; SINDEEVA, 1964).

It is the purpose of this paper to consider the manner of occurrence and the behavior of selenium during oxidation of selenium-bearing iron sulfide minerals and during formation of roll-type uranium deposits in sandstone. The interpretations are based on results of simple experiments and equilibrium calculations. Geochemical behavior of selenium in aerated natural waters, during diagenesis of sediments, and in volcanic activity will be described in subsequent papers.

THERMODYNAMIC CONSIDERATIONS

Eh-pH diagrams for selenium have been drawn previously (KRAUSKOPF, 1955; LAKIN, 1961; POURBAIX, 1963), but a more useful Eh-pH diagram than that of only the chemical species of selenium is a plot of predominant geochemical species: dissolved ions, minerals, or adsorbed ions. The association of selenium with iron sulfides and hydrous oxides and the commonly abundant occurrence of either pyrite or hydrous iron oxides in various near-surface environments lead to modified selenium Eh-pH diagrams which include these iron species and show the relationship of selenium to them. The most recent thermodynamic data available (GARRELS and CHRIST, 1965; KRAUSKOPF, 1967; MILLS, 1975; STULL and PROPHET, 1971; WAGMAN *et al.*, 1968, 1969) were used for the construction of diagrams from reactions which, although not experimentally determined, are balanced equations of Eh-pH relationships among species which are thermodynamically stable within

the ranges of oxidation potential and pH considered for each reaction. These reactions and pertinent oxidation potential-pH relations have been deposited with ASIS/NAPS.*

Effect of adsorption on stability of selenium species

If iron oxide is present in the system, specific adsorption of selenium oxyanions takes place by ion exchange with surface aquo ($-\text{Fe}-\text{OH}_2$), hydroxo ($-\text{Fe}-\text{OH}$), and ol ($-\text{Fe}-\text{O}^-$) groups of the hydrous iron oxides and of hematite (Fe_2O_3), which, in the presence of water, readily develops a hydrous surface film with adsorptive properties of goethite (FeOOH) (PARKS, 1965, 1967). Experimental work (CHAU and RILEY, 1965; ISHIBASHI *et al.*, 1967; HINGSTON *et al.*, 1968; HOWARD, 1969, 1972) indicates that adsorption on hydrous ferric oxides removes from 95 to 99% of the Se(IV) oxyanion from solutions of pH 8 and below; the proportion of adsorbed selenium seems to depend upon the surface characteristics of adsorbing ferric oxide.

The net effect of lowered Se(IV) concentration† is to broaden the range of oxidation potential over which Se(IV) can persist as the predominant and stable species (Fig. 1). Higher oxidation potentials are required to oxidize adsorbed Se(IV) to Se(VI) , and, in the presence of ferric hydroxide, elemental Se can be oxidized at lower potentials. Figure 1 also illustrates the almost quantitative adsorption of the Se(IV) oxyanions at pH 8 to essentially complete desorption at pH 11 (HINGSTON *et al.*, 1968; HOWARD, 1972). Low

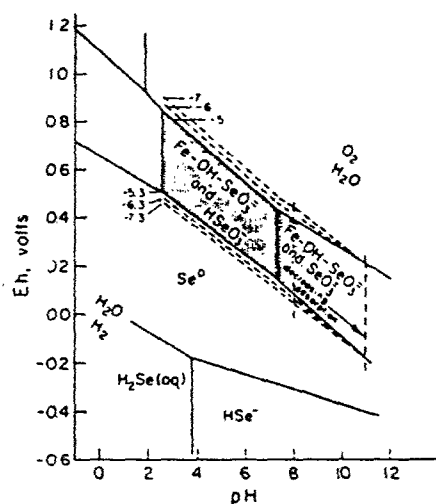


Fig. 1. The effect of adsorption of SeO_3^{2-} upon hydrous ferric oxide (represented by formula $\text{Fe}-\text{OH}-\text{SeO}_3^{2-}$) on Se(IV) stability fields. Dashed lines show resulting shift of oxidation potentials for $\text{Se(IV)}-\text{Se(VI)}$ and $\text{Se(IV)}-\text{Se(0)}$ couples; numbers are logarithms of Se(IV) concentration: 10^{-3} and $10^{-5.3}$ M, if not adsorbed; 10^{-6} and $10^{-6.3}$ M, if 90% adsorbed; and 10^{-7} and $10^{-7.3}$ M, if 99% adsorbed. Large shaded area depicts observed Eh-pH measurements of natural waters and of geologically important organisms (BAAS BECKING *et al.*, 1960). $Z(\text{Se}) = 2 \times 10^{-3}$ M, representing the range of selenium concentrations in natural waters, 10^{-3} – 10^{-9} M.

pH favors the H_2SeO_3 molecule, oxide dissociates to ions—the pH of crystalline form selenium oxyanion

Ferric-hydroxide an insoluble selenite concentration iron concentration the amounts to be ation, at any pH, $\text{Fe}_2(\text{OH})_4\text{SeO}_3$ (B slightly soluble se and TOMASHIVSKY

Geochemical stability

The Eh-pH diagram developed by Pourbaix for selenium minerals, the stable compound with iron sulfides uranium deposits in States (COLEMAN 1959; GRANGER, 19 U.S.S.R., with sulfid sandstones (BUR'Y, YANOVA, 1961, 19 iron selenide, FeSe Equilibrium relat

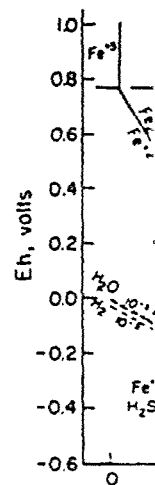


Fig. 2. Eh-pH diagram for selenium and iron. Numbers appear on the FeSe field is $10^{-3.87}$ M. FeSe smaller field width ratio (illustrated) represent the H_2S and reduction double-dot line iron, ES , 10^{-3}

* Order NAPS Document 03098 from ASIS/NAPS c/o Microfiche Publications, 440 Park Avenue, New York, NY 10016, remitting \$3.00 for the microfiche or \$5.00 for photocopies. Cheques should be made payable to "Microfiche Publications".

† In the wide range of ionic strengths of the several environments considered, the ionic activities of selenium species may vary by at least an order of magnitude from their ionic concentrations. For the geologic purposes of this paper, however, ionic concentrations will be considered equivalent to ionic activities.

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pH favors the freedom of Se(IV) in solution, as H_2SeO_3 molecules. The adsorbing hydrous ferric oxide dissociates under highly acid, oxidizing conditions—the pH of its dissociation depending upon the crystalline form of the oxide (Fig. 2A)—and the selenium oxyanion is no longer adsorbed.

Ferric-hydroxide adsorption, not the formation of an insoluble selenite, is responsible for controlling the selenite concentration in natural waters. Selenium and iron concentrations of natural waters are far below the amounts to be expected from equilibrium dissociation, at any pH, of either a basic ferric selenite, $\text{Fe}_2(\text{OH})_4\text{SeO}_3$ (BYERS *et al.*, 1938), or another very slightly soluble selenite, $\text{Fe}(\text{SeO}_3)_3$ (CHUKILANTSEV and TOMASHEVSKY, 1957; BUKETOV, 1965).

Geochemical stability of iron-selenide compounds

The Eh-pH diagram of selenium may be further developed by consideration of the low-temperature selenide minerals. The mineral ferroselite (FeSe_2) is the stable compound of iron and selenium and occurs with iron sulfides of very high selenium content in uranium deposits in sandstones of the western United States (COLEMAN and DELEVAUX, 1957; COLEMAN, 1959; GRANGER, 1966; HARSHMAN, 1966) and, in the U.S.S.R., with sulfide and uranium mineralization in sandstones (BUR'YANOVA and KOMKOV, 1955; BUR'YANOVA, 1961, 1969; KASHIRTSEVA, 1964); another iron selenide, FeSe , occurs as the mineral achavalite. Equilibrium relationships between these iron

selenides and iron sulfides are developed herein to assist in interpreting paragenesis of low-temperature pyrite-ferroselite-iron oxide-elemental selenium associations. Eh-pH stability relationships have previously been determined for clausthalite (PbSe) (TISCHENDORF and UNGENTHUM, 1964) and for some selenides of Fe, Zn and Cd (BUR'YANOVA, 1969) in order to interpret conditions of formation of these minerals and to compare their geologic stabilities in low-temperature ore deposits.

The rare occurrence of achavalite (FeSe), even in mineral associations of high selenium content, can be understood through examination of Fig. 2. Formation of FeSe by reduction is unlikely because the equilibrium oxidation potentials for reactions (2) and (3) lie below that at which water is reduced (Fig. 2A and 2B), except at lower concentrations of H_2S (Fig. 2C). Yet the stoichiometric excess of sulfur in the system which produces pyrite in low-temperature selenium-bearing mineral associations limits the stability range of FeSe to oxidation potentials at which pyrite is itself oxidized, a very small FeSe stability field [Fig. 2A and 2B, reactions (5), (6), and (7)]; FeSe can thus form by alkaline oxidation of $\text{FeS}-\text{Se}^{0}$ or $\text{FeS}-\text{HSe}^{-}$ mixtures. Initial formation of a hydrous iron oxide in the oxidation of selenium-bearing iron sulfide would permit formation of FeSe , but, since hematite (Fe_2O_3) is actually stable at an oxidation potential below that of the $\text{FeS}-\text{FeSe}$ couple (Fig. 2A), FeSe should eventually oxidize to Fe_2O_3 and to elemental

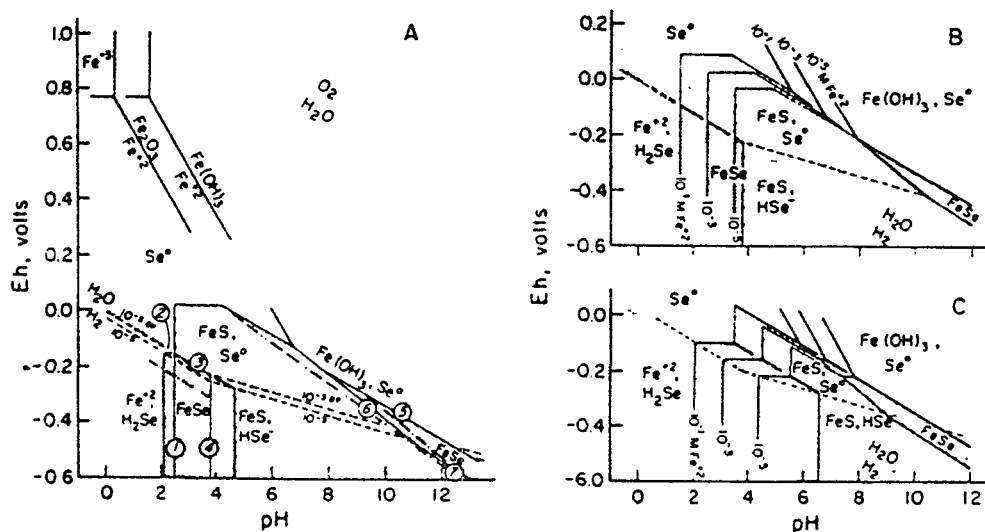


Fig. 2. Eh-pH relations of iron compounds which may form initially in an aqueous system of sulfur and selenium. The left-hand Fe-Se stability field is derived from half-cell reactions (1)-(4) (equation numbers appear on representative boundary lines; reactions are in the Appendix), and the right-hand FeSe field is determined by reactions (5)-(7). A. ΣS is 10^{-1} M; (Fe^{2+}), 10^{-3} M; and ΣSe , 10^{-3} and $10^{-3.87}$ M. FeSe and FeS coexist only when the (H_2Se)(H_2S) ratio exceeds $10^{-2.87}$, producing the smaller field within the left-hand FeSe stability field. This field expands with an increasing (H_2Se)(H_2S) ratio (illustrated at 10^{-3} M H_2Se) but disappears at any lower concentration ratio. Dashed lines represent the $\text{H}_2\text{Se}-\text{Se}^0$ and $\text{HSe}^{-}-\text{Se}^0$ couples at 10^{-3} and $10^{-3.87}$ M. Dash-dot lines are oxidation and reduction boundaries of FeS_2 (pyrite), showing that pyrite is more stable than FeS . Double-dot line is the $\text{FeS}-\text{Fe}_2\text{O}_3$ (hematite) oxidation boundary. B. Effect of concentration of dissolved iron. ΣS , 10^{-1} M; ΣSe , $10^{-3.87}$ M. C. Effect of lower concentrations of dissolved sulfur species. ΣS , 10^{-5} M; ΣSe , 10^{-5} M.

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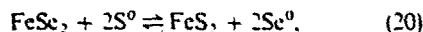
Recently published thermodynamic data (MILLS, 1975) facilitate calculation of the Gibbs free energy of formation for ferroselite (Table 1) according to the relationship

$$\Delta G_{f, \text{FeSe}_2}^0 = \Delta H_{f, 298}^0 - T\Delta S_{298}^0 \quad (8)$$

where $\Delta H_{f, 298}^0$ and ΔS_{298}^0 are the standard heat of formation (enthalpy) and formation-reaction entropy differences, respectively, for FeSe_2 at 298.15 K. Of two estimated heat of formation values, -21.5 ± 3 kcal/mole and -25.0 ± 3 kcal/mole (MILLS, 1975), Mills had adopted the latter, which was calculated from dissociation-pressure data. Standard entropy of ferroselite (20.75 cal/mole/K) was determined from heat-capacity measurements (GRONVOLD and WESTRUM, 1962). Another value for the free energy of formation of ferroselite, -34.06 kcal/mole, had been estimated earlier (LETNIKOV, 1965) from theoretical consideration of similarities of other thermodynamic properties of many chemical compounds of mineralogic importance.

The stability relations of ferroselite are plotted in Fig. 3 for each of these $\Delta G_{f, \text{FeSe}_2}^0$ values (Table 1); the free-energy value of -23.2 kcal/mole (MILLS, 1975), however, is used for subsequent interpretations of selenium geochemistry (Fig. 7). The geochemical behavior of ferroselite and elemental selenium observed in sandstone-type uranium deposits, as well as the geochemical character of iron sulfide oxidation, lend support to a ferroselite free-energy value of about -23 kcal/mole, rather than the earlier estimated -34 kcal/mole value; this evidence and its implications are discussed in subsequent sections of the paper.

Two stability fields for ferroselite, separated by the pyrite field, appear in Fig. 3A because, as determined from equilibrium consideration of the reaction



ferroselite is not stable with respect to pyrite when excess sulfur is present. Under these conditions, ele-

mental selenium is in equilibrium with pyrite and is probably incorporated in the pyrite since up to 3% by weight selenium can be held in solid solution in pyrite at the estimated formation temperature and pressure of the Colorado Plateau ores, 138°C and 800 atm (COLEMAN and DELEVAUX, 1957). Selenium exceeding this amount may occur as native selenium, or as ferroselite (COLEMAN, 1959) if excess ferrous iron is available.

The right-hand ferroselite stability field (Fig. 3A and 3B) is not large, yet it occupies a geochemically significant position, astraddle the boundary between pyrite and its immediate oxidation product, hydrous ferric oxide (Fig. 3A). The size and shape of the field are only slightly affected by concentration of selenium species [reactions (12) and (13)]. Eventual conversion of ferric hydroxide to the more stable hematite causes ferroselite to be oxidized at a lower redox potential; the ferroselite stability field is thus decreased in size (Fig. 3B).

The formation of ferroselite under naturally occurring reducing conditions, represented by the left-hand stability field (Fig. 3A), requires either that the value of $\Delta G_{f, \text{FeSe}_2}^0$ be more negative than the estimated -23 to -24 kcal/mole or that the concentration ratio of dissolved H_2Se to H_2S in the system be in excess of about $10^{-2.6}$. Otherwise, elemental Se within, or associated with, pyrite will be reduced directly to H_2Se or HSe^- . The selenium content of pyrite in some uranium deposits indicates that the $(\text{H}_2\text{Se})/(\text{H}_2\text{S})$ ratio may have indeed been great enough to form ferroselite from selenium-bearing pyrite or selenium-pyrite associations; for example, the Se/S ratio, by weight, of pyrite with 3% by weight selenium in solid solution is $10^{-1.03}$. With no further knowledge about low-temperature distribution of selenium between pyrite and an aqueous solution, however, this value can only suggest that the (H_2Se) concentration was large enough to permit reduction of elemental selenium to ferroselite.

OXIDATION OF IRON SULFIDE

Chemical weathering of iron sulfides by oxygenated

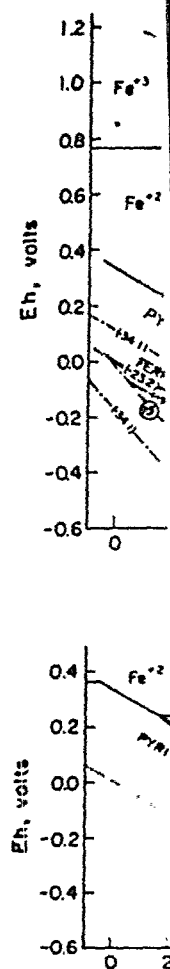


Fig. 3. Eh-pH stability diagrams for iron oxides. $\Sigma \text{Se} \geq 10^{-4}$ M. A. numbered for reactions (1) through (13) (see text). Left-hand ferroselite stability field is for $\Delta G_{f, \text{FeSe}_2}^0$ of -23.2 kcal/mole; right-hand ferroselite stability field is for $\Delta G_{f, \text{FeSe}_2}^0$ of -34.1 kcal/mole. For $\Delta G_{f, \text{FeSe}_2}^0$ of -23.2 kcal/mole, ferroselite is stable at lower concentrations of H_2Se (i.e., $(\text{H}_2\text{Se})/(\text{H}_2\text{S})$ ratio exceeds $10^{-2.6}$) and is shown at these Eh-pH values. For $\Delta G_{f, \text{FeSe}_2}^0$ of -34.1 kcal/mole, ferroselite is stable at lower concentrations of H_2Se (i.e., $(\text{H}_2\text{Se})/(\text{H}_2\text{S})$ ratio exceeds $10^{-1.03}$) and is shown at these Eh-pH values. The lines show displacement of the stability fields by the reaction of the ferroselite with H_2Se and HSe^- (see text).

Table 1. Values of free energy of formation of ferroselite calculated from reported heat of formation and entropy data

$\Delta G_{f, \text{FeSe}_2}^0$	$\Delta H_{f, 298}^0$	S^0	ΔS^0
kcal/mole	kcal/mole	cal/mole/°K	cal/mole/°K
-23.20	$-25.0 \pm 3^*$	20.75**	-6.05
-19.70	$-21.5 \pm 3^*$	20.75**	-6.05
-34.06	-36.56^\dagger	-	-8.4†

* MILLS (1975).

** GRONVOLD and WESTRUM (1962).

† LETNIKOV (1965).

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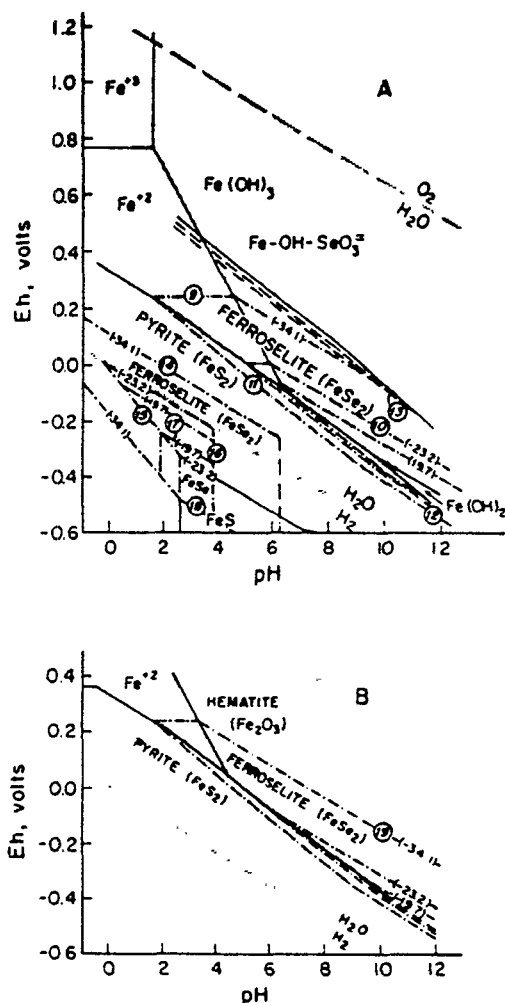
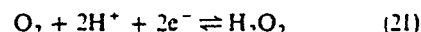


Fig. 3. Eh-pH stability relations of pyrite, ferroselite, and iron oxide. $\Sigma S = 10^{-4}$ M. $(Fe^{2+}) = 10^{-3}$ M, and $\Sigma Se \geq 10^{-4}$ M. A. Stability boundaries (dash-dot lines, numbered for reactions; see Appendix) of ferroselite, calculated for several values of $\Delta G_{FeSe_2}^0$, (indicated on boundary lines; see text), and of the iron selenide, FeSe. For the right-hand ferroselite stability field, only reactions (12) and (13) are dependent upon Se concentration (shown at 10^{-4} M). For $\Delta G_{FeSe_2}^0$ values of -19.7 and -23.2 kcal/mole, ferroselite is stable with respect to pyrite and H₂Se (left-hand stability field) only when the (H₂Se)/(H₂S) ratio exceeds $10^{-2.85}$ and $10^{-1.36}$, respectively. Stability fields are shown at these ratios ($10^{-1.85}$ and $10^{-2.36}$ M H₂Se); at lower concentrations this ferroselite field disappears. For $\Delta G_{FeSe_2}^0$ of -34.1 kcal/mole, ferroselite is stable at an (H₂Se)/(H₂S) ratio of $10^{-7.64}$ or greater; the field illustrated is for (H₂Se) = 10^{-4} M, extending into the HSe⁻-H₂S field (pH > 3.81). FeSe is stable with respect to H₂Se and FeS only at (H₂Se)/(H₂S) ratio of $10^{-3.87}$ or greater, for which its stability field is shown adjacent to and below the -23.2 and -19.7 FeSe₂ fields. Dashed lines show displacement of Se(IV) reduction due to SeO₃²⁻ adsorption (Fig. 1). B. Effect of formation of hematite on the ferroselite stability field.

waters establishes conditions of increased Eh and, in the absence of neutralizing carbonates or readily soluble silicates, very low pH (SATO, 1960). Reduced forms of selenium in diagenetic pyrite in sediments, in hydrothermal pyrite of sulfide ore bodies, and in

sandstone-type uranium deposits will be oxidized in response to the changing chemical conditions. The experiments with air oxidation of Fe-S-Se systems in water which are described below simulate the oxidation of ferrous sulfides and illustrate the consequent selenium behavior.

Experimental oxidation of ferrous iron (HUBER and GARRELS, 1953; SATO, 1960) has demonstrated two distinct courses of change in Eh and pH, one which is controlled by hydrolysis of the ferric iron produced during oxidation and paralleling the Fe(OH)₃-Fe²⁺ equilibrium boundary (Fig. 4, Trace A) and another in which alkaline conditions are maintained by a carbonate buffer (Fig. 4, Trace B). Further, measurements of Eh and pH of natural mine waters, experimental air oxidation of iron and manganese solutions, and theoretical considerations of chemical and mineral controls on the oxidation potential indicate that the maximum oxidation potential which can be attained by air oxidation of metal ions in aqueous media is that of the reversible O₂-H₂O₂ couple.



(SATO, 1960; Fig. 4), catalyzed in surface and groundwater environments by the iron- and manganese-oxide products of aeration. The oxidation experiments of this study (Table 2, Experiments I, II, V, and VII) demonstrated the same apparent controls by the O₂-H₂O₂ decomposition, by the Fe(OH)₃-Fe²⁺ equilibrium, and by a CaCO₃ (or NH₄OH) buffer.

Apparatus and instrumentation

The experimental apparatus consisted of an air-tight plastic cell (250 ml) with glass, platinum-inlay, and saturated-calomel electrodes; thermometer; burettes for addition of acid or base; gas-bubbling tube; and outlet tube connected to a water trap. Electrochemical output was monitored by strip-chart recorders through Beckman Zeromatic pH meters, and the solution was continuously agitated with a magnetic stirrer. The compositions and results of each experiment, prepared from various reagents in 200 ml of distilled water, are summarized in Table 2 and Fig. 4.

Selenium was determined by X-ray fluorescence (XRF) using a vacuum X-ray spectrograph (Philips Electronics Instruments) with a tungsten target tube and Ni-foil filter to mask W L_α radiation (HOWARD, 1969). Selenium precipitates on MF-Millipore[®] filters were mounted in Mylar film on plastic sample holders (Spex Industries, Inc.) for X-ray analysis.

Analytical procedures

Oxyselenium anions were desorbed from ferric hydrous oxides by shaking with 0.5 N ammonium hydroxide-ammonium acetate; selenium in the 3-μm filtrate was reduced to the elemental state by either sulfur dioxide-hydroxylamine hydrochloride treatment or stannous chloride (HILLEBRAND *et al.*, 1953; JOHNSON, 1958; ROSENFELD and BEATH, 1964) and collected on a 0.45-μm membrane filter for quantitative XRF determination (CHIAN, 1963). Dissolved selenium forms present in aqueous phases of experimental systems were similarly reduced after removal of solid materials by centrifugation and filtration. Elemental selenium was extracted from solid phases of experimental systems with carbon disulfide; evaporation of this

Table 2. Experimental air oxidation and pH variation of prepared aqueous Fe-S-Se systems*

Experiment	System composition	Procedure	Results
I	Fe-S-Se-CaCO ₃ : (500 ppm Fe ³⁺ , 10 ppm SeO ₃ ²⁻ , 580 ppm S ²⁻ , excess CaCO ₃).	Reduction of Fe and Se and precipitation of FeS with Na ₂ S; addition of CaCO ₃ ; air bubbling. Duration, 10½ hours.	Oxidation of FeS to Fe(OH) ₃ and some Se ⁰ to SeO ₃ ²⁻ .
II	Fe-quartz-feldspar: (0.01 M Fe ³⁺ ; excess ground quartz and feldspar).	Reduction of Fe with H ₂ gas; increase of alkalinity and precipitation of ferrous hydroxide (?) with NaOH; air bubbling. Duration, 17 hours.	Oxidation of Fe(OH) ₃ to Fe(OH) ₃ .
III	Fe(OH) ₃ -SeO ₃ ²⁻ : (3.45 mg Fe(OH) ₃ /ml; 20 ppm SeO ₃ ²⁻).	Adjustment of pH with NaOH and HCl.	See Fig. 5.
V	Fe-S-Se-CaCO ₃ : (same as for Experiment I).	Same as for Experiment I. Duration, 365 hours. Aliquots withdrawn for Se analysis (Table 3).	Same as for Experiment I; see Table 3.
VI	Fe-S-Se-CaCO ₃ : (Experiment V).	Adjustment of pH with HCl.	See Fig. 5.
VII	Fe-S: (1000 ppm Fe ³⁺ ; 0.1 M H ₂ S (sard.)).	Reduction of Fe with H ₂ S gas; addition of NH ₄ OH and precipitation of FeS; air bubbling. Duration, 2½ days.	Oxidation of FeS to Fe(OH) ₃ .
VIII	Fe(OH) ₃ -SeO ₃ ²⁻ : (10 ppm SeO ₃ ²⁻ , added to Fe(OH) ₃ slurry of Experiment VII).	Adjustment of pH with HCl. Aliquots withdrawn for Se analysis (Table 4 and Fig. 6).	See Table 4 and Fig. 5.

* A more detailed tabulation of experimental composition, procedure, and results is available with the previously cited NAPS document.

extract under high-purity nitrogen left a precipitate of red amorphous selenium, to be dissolved with concentrated sulfuric or nitric acid, diluted, and reduced to elemental selenium for X-ray determination. Precision of XRF analysis for precipitated elemental selenium (predominantly the standard counting error) is very low for a few tenths of a microgram of selenium, but improves to 15% and better for amounts of 1 µg or greater (HOWARD, 1969, 1975).

Results of experiments

Selenium added as Se(IV) to the systems (Experiments I, II, and V; Fig. 4) was reduced to elemental selenium as the oxidation potentials were lowered but was not again oxidized to Se(IV) by the air passed through the suspension, although the systems rapidly attained their maximum oxidation potentials—which were similar to those of natural surface waters and which lay within the SeO₃²⁻ stability field—and remained at these high potentials during the longest portion of the experiment. Bubbling of air through an Fe-S-Se-CaCO₃ system for a period of 365 hr (15 days) failed to oxidize the elemental selenium to its SeO₃²⁻ form (Experiment V; Table 3); similarly, elemental sulfur formed from oxidized FeS was not appreciably oxidized to sulfate. [This very high oxidation potential, the same as that achieved by SATO (1960) in 14 hr of air bub-

bling, may be due to a slowing of the rate of the O₂-H₂O₂ decomposition reaction whenever the oxidized form of the catalytic element—in this instance ferric iron—is in a solid form (SATO, 1960); perhaps continued aging of the Fe(OH)₃ precipitate slows the reaction rate even further, permitting higher oxidation potentials to be attained.] More time and possibly bacterial activity are needed for selenium oxidation. The higher Eh and pH conditions of the Se(VI) stability field were never reached in the experimental oxidation of a reduced system by air. Perhaps, therefore, air oxidation cannot produce SeO₄²⁻ during natural weathering of selenium and iron-sulfide mineral associations.

Experiment VIII provides an estimation of the extent of adsorption of SeO₃²⁻ on the Fe(OH)₃ product of FeS oxidation with increase in acidity of the medium. Sodium selenite was added to the air-oxidized system (Experiment VII, Table 2), and, after successive pH adjustments and 12-hr equilibration periods, aliquots of slurry were analyzed for soluble SeO₃²⁻, adsorbed SeO₃²⁻, SeO₄²⁻, and elemental selenium (Table 4 and Fig. 6). The dominant species found in each aliquot was in accord with the expected form of selenium (Fig. 5 and Table 4); no SeO₄²⁻ was detected. The amounts determined of each form of selenium roughly correspond to those to be expected, theoretically, for the Eh-pH course of Experiment VIII

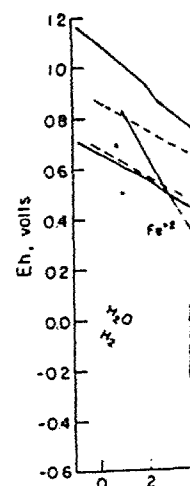
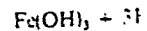


Fig. 4. Traces of experiment solutions. Experiments V: Fe-S-Se-CaCO₃ system; and VII: Fe-S system; selenium species formed for reference: (Fe²⁺) ESe = 10⁻⁴ M. Also, extended through the 1 line). Traces A and B (of 0.01 M ferrous-iron; shown for P_{O₂}:(H₂O₂)).

(Fig. 6), although the a too large at pH 8.6, and. The Eh variations at pH adjustments (Fig. 5) of the platinum electrode the oxidation potential tial

$$Eh = E^0 - 0$$

where the value of the depends upon the part ferrous ion reaction su



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S-Se systems*

Results

oxidation of FeS to
Fe(OH)₃ and some
Se⁰ to SeO₃²⁻.
Oxidation of Fe(OH)₃
to Fe(OH)₃.

See Fig. 5.

Same as for Experiment

I; see Table 3.

See Fig. 5.

Oxidation of FeS to
Fe(OH)₃.

See Table 4 and Fig. 5.

able with the previously

he rate of the O₂-H₂O₂ the oxidized form of the ferric iron—is in a solid aged form of the Fe(OH)₃ even further, permitting attained.] More time and needed for selenium oxidation conditions of the Se(VI) in the experimental oxidation. Perhaps, therefore, air during natural weathering mineral associations. stimulation of the extent of Fe(OH)₃ product of FeS of the medium. Sodium buffered system (Experiment I) pH adjustments and lots of slurry were analyzed for SeO₃²⁻, SeO₄²⁻, and elemental Se. The dominant species found with the expected (Table 4): no SeO₄²⁻ was found of each form of those to be expected. Experiment VIII

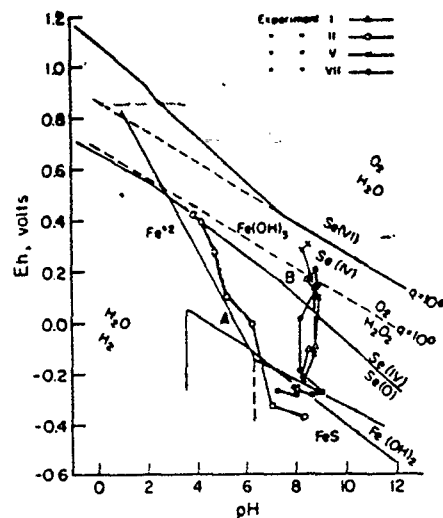


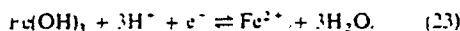
Fig. 4. Traces of experimental air oxidation of ferrous-iron solutions. Experiments I, II, V and VII (Table 2). I and V: Fe-S-Se-CaCO₃ system; II: Fe-quartz-feldspar system; and VII: Fe-S system. Stability fields of iron and selenium species formed during the experiments are plotted for reference: (Fe²⁺) = 10⁻² M, ΣS = 10⁻² M, and ΣSe = 10⁻⁵ M. Also, the Fe²⁺-Fe(OH)₃ boundary is extended through the FeS stability field (vertical dashed line). Traces A and B (SATO, 1960) illustrate air oxidation of 0.01 M ferrous-iron solutions. The O₂-H₂O₂ couple is shown for P(O₂):(H₂O₂) ratios, *q*, of 1 and 10⁶ (SATO, 1960).

(Fig. 6), although the amounts of free SeO₃²⁻ seem much too large at pH 8, 6, and 4.

The Eh variations that occur with these experimental pH adjustments (Fig. 5) are not fully understood. Coating of the platinum electrode with ferric oxide should cause the oxidation potential to approximate the Nernst potential

$$Eh = E^0 - 0.177 \text{ pH} - 0.059 \log (\text{Fe}^{2+}). \quad (22)$$

where the value of the standard electrode potential, *E*⁰, depends upon the particular iron oxide in a ferric oxide-ferrous ion reaction such as



Even if the ferrous-ferric reaction should be too slow to

be observed in the course of the experiment—and such should not be the case (DOYLE, 1968)—and if no other oxidation-reduction couple exerts a pH-dependent control, the Eh should vary according to

$$Eh = E_{\text{H}^+/\text{H}_2}^0 - 0.003 (P_{\text{H}_2}) - 0.059 \text{ pH}. \quad (24)$$

the oxidation potential of the H⁺-H₂ equilibrium. Yet the measured Eh-pH slopes (Fig. 5) are neither -0.177 nor -0.059 V per pH unit. The oxidation potential did finally rise to higher Eh values (Experiments VI and VIII, Fig. 5), with a slope between the final and the initial points of about -0.059 pH. Perhaps slow equilibration of ferric hydroxide to the added acid, by some one-to-one H⁺-e⁻ transfer reaction, caused the observed Eh-pH variations.

In summary, the experimental oxidation of aqueous Fe-S-Se systems suggests the following conclusions about the behavior of the selenium during natural oxidation of seleniferous iron sulfide:

(1) The higher-valence-state stability fields of selenium—at least Se(IV)—can be attained by air oxidation of a reduced aqueous Fe-S-Se system, either acid or alkaline, but elemental selenium is only slowly oxidized to SeO₃²⁻. Lowering of the Eh-pH conditions into the elemental-selenium field, however, easily and rapidly reduces oxidized selenium.

(2) With oxidation of selenium in iron-sulfide systems, buffered at pH 8-9 by CaCO₃, some selenium should become mobile, because the SeO₃²⁻ ions are not adsorbed strongly at the higher pH, at least pH 9-10. Adsorption at lower pH was not adequately demonstrated by these particular experiments, but it has been demonstrated elsewhere (HINGSTON *et al.*, 1968; HOWARD, 1972). Oxidation under acid conditions should produce HSeO₃⁻, which will be strongly adsorbed by Fe(OH)₃ at low pH and immobilized.

(3) The stability field of Se(VI) may not be attained by air oxidation of sulfides, so that formation of the selenate (SeO₄²⁻) species, even under alkaline conditions, should not take place under natural conditions of weathering.

DISCUSSION

The geochemistry of selenium is summarized by the Eh-pH diagram of Fig. 7, which is based on the ex-

Table 3. Amounts of selenium in 20.0-ml aliquots of slurry withdrawn during air oxidation of aqueous Fe-S-Se-CaCO₃ system, Experiment V. Aliquots were centrifuged and the supernatant filtered through Millipore[®] 3-μm filters. The adsorbed SeO₃²⁻ and the elemental Se⁰ were removed from the Fe(OH)₃ precipitate by successive extractions with NH₄OH-NH₄OAC and CS₂, respectively. The 20.0-ml aliquots should contain 200 μg selenium

Time elapsed during oxidation, hrs.: mins.	pH	Eh, mv.	Identity of suspended solid	Selenium, μg			
				>3-μ ppt.	3-μ filtrate	ads. SeO ₃ ²⁻	elem. Se ⁰
7:20	8.53	175	Fe(OH) ₃ -S ⁰	0.7	0.7	0.6	> 53
50:55	8.33	280	Fe(OH) ₃ -S ⁰	4.3	0.9	0.2	>135
364:55	8.43	305	Fe(OH) ₃ -S ⁰	1.7	0.8	0.2	>145

Table 4. Amounts of selenium in 20.0-ml aliquots of $\text{Fe}(\text{OH})_3\text{-S}^0$ slurry (Experiment VIII) withdrawn during increasing acidification of aqueous FeS system previously oxidized by air bubbling (Experiment VII). Separation of the selenium forms was identical to that of Experiment V (Table 3)

pH	S, uv.	Selenium, μg^a		
		dissolved SeO_3^{2-} (0.45-u filtrate)	adsorbed SeO_3^{2-} ($\text{NH}_4\text{OH-NH}_4\text{OAC}$ extracted)	elemental Se^0 (CS_2 extracted)
9.87	192	82.2	0.7	0.4 ^c
8.07	221	77.9	13.5	5.2 ^c
6.17	253	14.4	a ^b	a ^b
3.96	273	13.4	0.3	107.4
2.07	411	0.1	1.2	157.5
2.16	547	0.3	1.2	171.3

^a Total 200 μg in each aliquot was never recovered, indicating need for improvement of separation techniques.

^b Extraction was not successful.

^c Some extracted material lost after the evaporation of CS_2 .

perimental work and theoretical computations presented herein and elsewhere (HOWARD, 1972) and upon the geologic considerations which follow. Of major interest are the low-temperature oxidizing and reducing environments in the vicinity of ore bodies which contain iron sulfides. Adsorbed SeO_3^{2-} , selenium-bearing pyrite, and ferroselite are important geochemical forms of selenium in these environments.

Ferroselite in sandstone-type uranium deposits occurs near the interface between altered sandstone (which contains goethite, limonite, and hematite) and either pyritic uranium ore or unoxidized barren sandstone containing pyrite with low selenium content (GRANGER, 1966; HARSHMAN, 1966; GRANGER and

WARREN, 1969). Associations both of ferroselite-pyrite (and marcasite) and of goethite-hematite-ferroselite are seen, implying that selenium and ferrous iron, released in the destruction of pyrite by oxidizing solutions, have combined to form the minute stellate crystals of ferroselite (GRANGER, 1966). Ferroselite, then, is stable in an environment more oxidizing than is pyrite. If the Gibbs free energy of ferroselite were not more negative than about -10 kcal/mole, there would not be an FeSe_2 stability field between the pyrite and ferric hydroxide fields (Figs. 3 and 7). Stability of ferroselite at pH below 8 (produced by oxidation of pyrite and subsequent hydrolysis of ferric iron) further requires that its free energy of formation be more negative than -15 kcal/mole:

Ferroselite has been synthesized at pH ranging

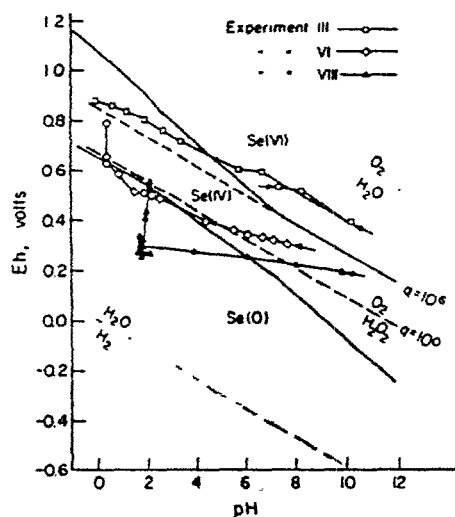


Fig. 5. Eh variation with experimental adjustment of the system pH, Experiments III, VI, and VIII (Table 2). Arrows show direction of pH change. Stability fields of selenium (10^{-5} M) are plotted for reference.

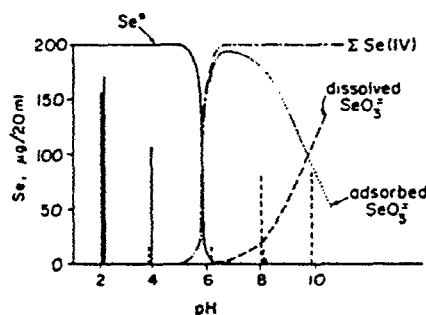


Fig. 6. Influence of pH upon form of selenium (Experiment VIII, Tables 2 and 4). Amounts found by analysis are shown by vertical lines: elemental Se, solid lines; dissolved SeO_3^{2-} , dashed lines; and adsorbed SeO_3^{2-} , dotted lines. The expected relative proportions of selenium forms, plotted as curves, were determined from the Nernst potential of Trace VIII, Fig. 5 (0.330-0.14 pH V) and from adsorption studies with selenite and hydrous ferric oxide (HINGSTON *et al.*, 1968; HOWARD, 1972).

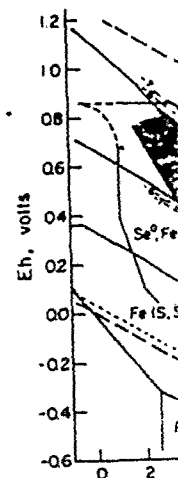


Fig. 7. Eh-pH diagram surface aqueous environment calculated for ΔG^0 of -1 dot line within the FeS boundary (reaction 19 pyrite field represents couples. Dashed line: Se(IV)-Se(VI) boundary by adsorption lines bound a "transition" with increasing alkali 10^{-1} M; and ΣSe , 10

from 7 to 9 and at 1968), simulating the roll-type uranium (1969). No ferroselite (WARREN, 1968). The solid FeS with a solid sodium sulfite with be an equilibrium sodium selenosulfate potential of reported, the near-its formation are in the stability field of ferroselite.

A ferroselite state of -23.2 kcal/mole than that for the ferroselite inferred from its field to pH 5, lower than be synthesized (WARREN, 1968). The oxidation potential of side the ferroselite free energy of ferroselite than -23.2 kcal/mole (WARNOVA (1969)), the under which ferroselite even further, including reducing conditions, suggesting that ferroselite more reducing than reported, however

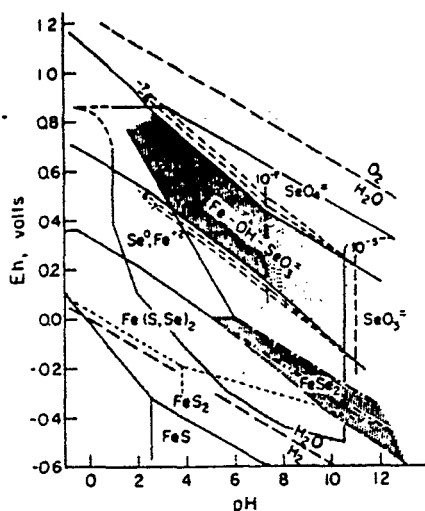


Fig. 7. Eh-pH diagram of predominant Se species in earth-surface aqueous environments. FeSe_2 (ferroselite) field calculated for ΔG° of -23.2 kcal/mole. Double-dash, double-dot line within the ferroselite field is $\text{FeSe}_2 \cdot \text{Fe}_2\text{O}_3 \cdot \text{SeO}_3^{2-}$ boundary (reaction 19, Fig. 3B); short-dash line within the pyrite field represents the $\text{Se}^0\text{-H}_2\text{Se}$ and $\text{Se}^0\text{-HSe}^-$ couples. Dashed lines parallel to the Se(0)-Se(IV) and Se(IV)-Se(VI) boundaries show displacement of these couples by adsorption on ferric hydroxide; vertical dashed lines bound a "transition" zone of decreasing adsorption with increasing alkalinity (Fig. 1). (Fe^{2+}) is 10^{-3} M; ΣS , 10^{-1} M; and ΣSe , 10^{-3} M.

from 7 to 9 and at temperatures of 80°C (WARREN, 1968), simulating the ore solutions which formed the roll-type uranium deposits (GRANGER and WARREN, 1969). No ferroselite was produced at pH 6 or below (WARREN, 1968). The synthesis involved reaction of solid FeS with a solution prepared by reaction of 1 M sodium sulfite with elemental selenium, purported to be an equilibrium mixture of sodium sulfite and sodium selenosulfate, Na_2SSeO_3 . Although the oxidation potential of these ferroselite syntheses is not reported, the near-neutral to alkaline conditions of its formation are in accord with the theoretical stability field of ferroselite (Figs. 3 and 7).

A ferroselite stability field constructed at $\Delta F_{\text{FeSe}_2}^\circ$ of -23.2 kcal/mole (Table 1; MILLS, 1975) is larger than that for the free-energy value of -15 kcal/mole inferred from its field occurrence (Fig. 3). It extends to pH 5, lower than that at which ferroselite could be synthesized (WARREN, 1968), but perhaps the oxidation potential of the synthesis experiments lay outside the ferroselite domain at pH 6 and below. If the free energy of ferroselite were to be more negative than -23.2 kcal/mole [as, for example, that of BUR'YANOVA (1969)], the range of geochemical conditions under which ferroselite can form would be expanded even further, including a stability domain at acid, very reducing conditions (Fig. 3). No field evidence suggesting that ferroselite forms at Eh-pH conditions more reducing than the pyrite stability field has been reported, however, and such acidic reducing condi-

tions are unlikely in natural waters (BAAS BECKING *et al.*, 1960; SATO, 1960).

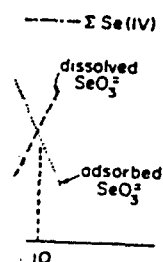
Oxidation of selenium-bearing sulfides

The Eh-pH conditions in the vicinity of an oxidizing sulfide body should, according to experimental results, vary along one of two courses (Fig. 4): increasing oxidation of the ferrous iron of pyrite and consequent ferric-iron hydrolysis makes the medium increasingly acid, and the changing Eh and pH will follow the $\text{Fe(OH)}_3\text{-Fe}^{2+}$ equilibrium. If, however, calcite or reactive silicates are present to neutralize the acid, the oxidation potential will rise, but the waters will remain alkaline or neutral. These paths can be transposed to Fig. 7 from Fig. 4 for reference.

Oxidation of seleniferous pyrite will release selenium from the pyrite structure. At low potentials the selenium may combine with ferrous iron to form ferroselite, such as that associated with some sandstone uranium deposits of the western interior United States. Further oxidation will eventually form elemental selenium, which may persist to oxidation potentials well above the upper oxidation limit of pyrite (Fig. 7), associated with limonite and jarosite. Experimental oxidation to SeO_3^{2-} takes place only very slowly, leaving most of the selenium in the native state, and elemental selenium has been found in several natural limonite materials of weathered sedimentary rocks (SAVIL'EV, 1963; HOWARD, 1969). As the Se(0)-Se(IV) couple is attained, and selenium is oxidized to HSeO_3^- under acid conditions, it should be adsorbed on the limonite as demonstrated by numerous adsorption experiments with hydrous ferric oxides and ferric-oxide-bearing rock materials (BYERS *et al.*, 1938; OLSON, 1939; OLSON and JENSEN, 1940; PLOTNIKOV, 1958, 1960, 1964; HINGSTON *et al.*, 1968; CARY *et al.*, 1967; HOWARD, 1969, 1972) and experimental extractions of selenite from limonitic materials (GEERING *et al.*, 1968; HOWARD, 1969).

Whether selenium can be oxidized by aerated waters to the extent necessary to form the mobile SeO_4^{2-} ion is still uncertain. Selenate has been reported as a soluble constituent of soils, identified on the basis of its chemical behavior (that is, it is not reduced by SO_2 in sulfuric acid solutions) (ROSENFELD and BEATH, 1964; CARY *et al.*, 1967), and LAKIN (1961) has suggested that, in an alkaline environment, SeO_3^{2-} is oxidized to the Se(VI) state, SeO_4^{2-} , which neither is strongly adsorbed nor forms insoluble compounds and is, therefore, a mobile ion. Catalytic decomposition of the oxidation by-product, H_2O_2 , however, seemingly prevents attainment of oxidation potentials high enough to form SeO_4^{2-} during aeration of natural waters (SATO, 1960). Even with removal of H_2O_2 and reduced ionic species in migrating waters and subsequent replenishment by oxygenated water, the remaining ferric-hydroxide oxidation products will catalyze the decomposition of H_2O_2 produced in subsequent oxidation, again inhibiting the oxidation process. Oxidation experiments

th of ferroselite-pyrite e-hematite-ferroselite um and ferrous iron, ite by oxidizing solu- : minute stellate crys- (66). Ferroselite, then, ore oxidizing than is f ferroselite were not -1 al/mole, there field between the pyr- gs. 3 and 7). Stability duced by oxidation ylysis of ferric iron) rgy of formation be ile. ized at pH ranging



elenium (Experiment and by analysis are solid lines; dissolved SeO_3^{2-} , dotted lines.elenium forms, plot-the Nernst potential V) and from adsorp-is for oxide (HING-

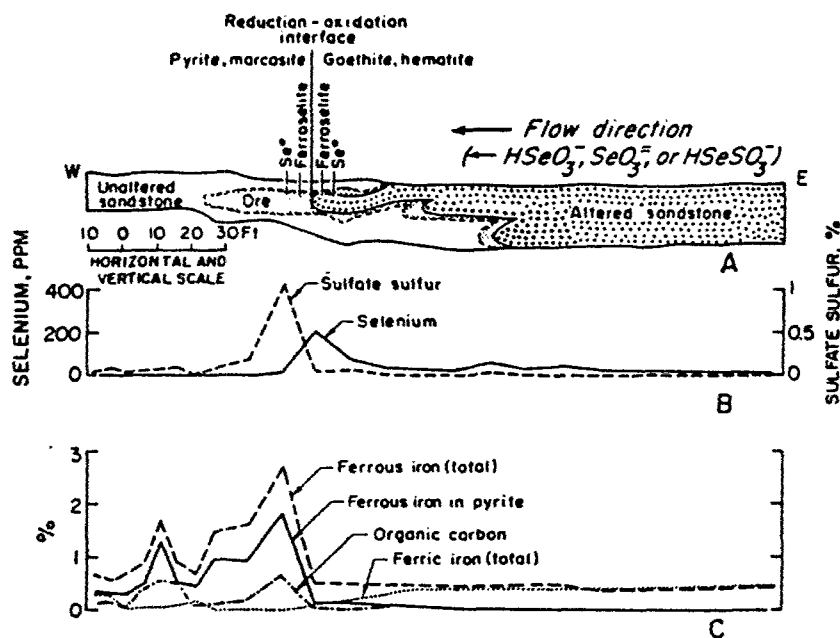


Fig. 8. Vertical section through roll-type uranium ore body and horizontal distribution of selected geochemical species through the tongue of altered sandstone and ore and into the unaltered sandstone. Arrow shows direction in which ore solution moved. [Modified from HARSHMAN (1966).]

with clausthalite (PbSe), selenium-containing galena (PbS), and SeO_3^{2-} -ferric hydroxide systems have also reportedly failed to put selenium into solution as the SeO_4^{2-} ion (D'YACHKOVA, 1965; KULIKOVA, 1966). Mobility of selenium as a dissolved ion does not require oxidation to SeO_4^{2-} , however; selenite, which does not form an insoluble ferric selenite but is adsorbed on hydrous ferric oxide at pH below 8, is increasingly desorbed from pH 8 to 11, is not adsorbed at all at pH above 11, and becomes, therefore, free for transportation in alkaline waters.

Such should be the behavior of selenium during oxidation of its pyrite host, whether in sulfide ore bodies or in diagenetic pyrite. Acid conditions should prevail in the weathering zone of large pyrite bodies, with subsequent accumulation of Se^0 and SeO_3^{2-} in the limonite gossan. Oxidation of selenium-bearing sedimentary pyrite grains (and organic material), if neutralized by calcium carbonate of the sediments, and, more slowly, by reaction with the silicates, should release SeO_3^{2-} to migrate until adsorbed by limonite in waters made more acid, perhaps by atmospheric carbon dioxide. The localized environment of a diagenetic pyrite nodule undergoing oxidation, however, might remain acid, perhaps affected by its limestone host rock only around the periphery of the nodule. Selenium should remain in the nodule as adsorbed SeO_3^{2-} or elemental selenium; high selenium contents are indeed reported for goethite pseudomorphs after pyrite nodules in certain limestones (WILLIAMS and BYERS, 1934; HOWARD, 1969).

Selenium behavior in the vicinity of uranium ore deposits

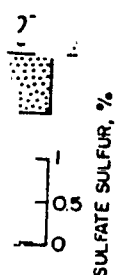
The roll-type uranium ore bodies of Wyoming and

Texas and tongue-like ores in the Colorado Plateau are concentrations of uranium and associated metals (e.g. iron, molybdenum, vanadium, selenium) in gently dipping, permeable sandstone units which are confined between units of much lower permeability. These bodies, elongated parallel to the plane of stratification, are crescent-shaped in vertical cross-section (Fig. 8). The up-dip and concave side of the ore body forms a sharp interface with sandstone altered by oxidation; down dip the sandstone is unaltered by groundwaters, iron is in the ferrous state in silicates and in diagenetic pyrite, and abundant carbonaceous plant materials occur throughout, all attesting to the prevalence of reducing conditions prior to formation of the roll deposits. These deposits probably formed as oxidizing meteoric solutions moved through the host sandstone, dissolving pyrite and other readily oxidized minerals (GRANGER and WARREN, 1969, 1974). The solution gradually lost its oxidizing potential through these reactions and passed into the reducing environment of the host rock, depositing reduced iron, selenium, and uranium minerals. These percolating ground waters have continually brought into solution and subsequently deposited the minerals at the migrating interface between the oxidized and reduced environments, increasingly concentrating those elements which are immobile under reducing conditions (GRUNER, 1956). Selenium is concentrated (Fig. 8) as elemental selenium in oxidized sandstone near the deposit, as ferroselite in both goethite-hematite and pyrite-marcasite associations at the oxidized-reduced interface, and as ferroselite and native selenium with the pyrite-marcasite and uraninite-coffinite assemblages of the ore body (GRANGER, 1966; HARSHMAN, 1966; GRANGER and WARREN,

1969). Tabular ore deposit, New Mexico, has been redistributed by bodies with characteristic type deposits (GRANGER,

Eh and pH of mixtures of uranium and sulfuric acid, and temporally delineated from Eh-pH mine waters, experimental field of mineral in the oxidation potential reduced toward either reducing conditions should be according to the but, similar to those potentials within the amounts, in the mixture species introduced by species already present fluids or pressures which take reactions and fluid-host up reducing agents (clays, carbonaceous bacterial activity or both oxidized and reduced mate oxidized species CO_2 —are essentially dation potential of WARREN, 1969). The HS^- , H_2S , $\text{S}_2\text{O}_3^{2-}$ —dation actually made. Only complete oxid agents by the migration more oxidizing agent tial.

Selenium, in low reduced rock (HARSHMAN, 1966) as either ferroselite, sulfur within the pyrite (GRANGER, 1957). As the ore solution moved through the host rock and more oxidizing, pyrite would be formed from selenium (Fig. 7), or talcs of ferroselite (GRANGER, 1966) are served after oxidation consequent rise in Eh of the ferroselite, produced selenium. Subsequent of even higher oxidation potential selenium to sandstone. Some, perhaps most alkaline oxidizing fluids oxides with some selenium-bearing solution migration of the host rock by H_2S generated by



on of selected
red sandstone.
(1966).]

the Colorado Plateau and associated metals (including selenium) in gently sloping units which are characterized by lower permeability. In a vertical cross-section of the ore body, the host rock is unaltered by oxidation, as is the state in silicates and carbonaceous material, attesting to the fact that prior to formation of the ore, the host rock was probably formed and moved through the host rock and other readily oxidized materials (GRANGER and WARREN, 1969). As the oxidizing potential passed into the host rock, depositing minerals. These minerals were continually brought to the surface and concentrated under reducing conditions. The ore is concentrated in oxidized sandstone with goethite-hematite and native copper and uraninite (GRANGER and WARREN, 1969).

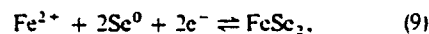
1969). Tabular ore deposits of the Ambrosia Lake district, New Mexico, have in some places been altered and redistributed by oxidizing waters to produce ore bodies with characteristics similar to those of the roll-type deposits (GRANGER and WARREN, 1974).

Eh and pH of meteoric solutions in the vicinity of uranium and sulfide ore deposits, which vary spatially and temporally over a wide range, have been delineated from Eh-pH measurements of oxidizing mine waters, experimental oxidation systems, and stability field of minerals which are sensitive to changes in the oxidation potential (SATO, 1960). Changes induced toward either more oxidizing or more reducing conditions should follow paths of Eh-pH change, according to the buffering capacity of the environment, similar to those depicted in Fig. 4. Oxidation potentials within the front result from the relative amounts, in the mixing fluids, of active oxidizing species introduced by the ore solution and of reducing species already present in the host rock and its contained fluids or produced by oxidation-reduction reactions which take place within the mixing solutions and fluid-host medium. Oxidizing reactions use up reducing agents of the host rock (pyrite, ferrous clays, carbonaceous material) and produce, either by bacterial activity or in biologically sterile reactions, both oxidized and reduced chemical species. The ultimate oxidized species— SO_4^{2-} , ferric hydroxide, CO_2 —are essentially inert and do not elevate the oxidation potential of the solution (GRANGER and WARREN, 1969). The reduced species—such as Fe^{2+} , HS^- , H_2S , $\text{S}_2\text{O}_3^{2-}$ —are reactive, however, so that oxidation actually maintains a reducing environment. Only complete oxidation or removal of all reducing agents by the migrating fluid and introduction of more oxidizing agents will raise the oxidation potential.

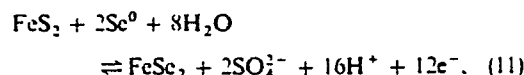
Selenium, in low concentration in the unaltered, reduced rock (HARSHMAN, 1966, 1974), should occur as either ferroselite, or, more likely, substituting for sulfur within the pyrite (COLEMAN and DILEVAUZ, 1957). As the ore solution intrudes the non-mineralized host rock and conditions become increasingly more oxidizing, pyrite should be destroyed and ferroselite be formed from the released ferrous iron and selenium (Fig. 7), or perhaps the delicate stellate crystals of ferroselite observed in these deposits (GRANGER, 1966) are exsolution forms in pyrite preserved after oxidation. More intense oxidation and consequent rise in oxidation potential should destroy the ferroselite, producing ferric oxide and elemental selenium. Subsequent encroachment of ore solutions of even higher oxidation potential will oxidize the elemental selenium to a selenite form, SeO_3^{2-} or HSeO_3^- . Some, perhaps most, SeO_3^{2-} ions will move with the alkaline oxidizing fluid, leaving behind hydrous ferric oxides with some selenite absorbed. As this SeO_3^{2-} -bearing solution moves on into the reducing environment of the host rock, its Eh will be lowered both by H_2S generated by sulfate-reducing bacteria in the

host rock and from dissociation of unstable sulfur species (for example, SO_3^{2-} and $\text{S}_2\text{O}_3^{2-}$) which are intermediate products of pyrite oxidation (GRANGER and WARREN, 1969). Such dissociations produce H_2S and HS^- , which lower the Eh of the solution, and inert SO_4^{2-} , which exerts no control over the oxidation potential (GRANGER and WARREN, 1969). Selenite is reduced at the lowered Eh to elemental selenium and precipitated at the margin of the oxidized host rock with the ferric oxides formed from pyrite, the oxygen-acceptor in the reduction of SeO_3^{2-} . Other chemical species which require lower Eh for their reduction, such as those of uranium, vanadium (GARRELS and CHRIST, 1965), molybdenum, and iron, will move to the more reducing environment beyond the zone of selenium accumulation and be deposited (KASHIRTSOVA and TROSTYANSKIY, 1970). The solution, depleted of its metals and oxidizing capability, passes on into the reduced rock.

Elemental selenium will accumulate until the reducing agents in the rock either are oxidized or coated protectively with oxidized material. The ore fluid which subsequently enters this zone can then maintain its moderately elevated Eh and can bear SeO_3^{2-} (and other oxygenated metal ions) without reduction beyond and into the region of lower oxidation potential. This SeO_3^{2-} is reduced to form ferroselite and ferric oxides coevally by reaction with free ferrous iron and pyrite. Ferroselite formation is represented summarily for thermodynamic consideration (Figs. 3 and 7) by the reactions



and



although these reactions may not depict actual reaction mechanisms. Selenium may, in solutions with limited oxygen supply and moderately low Eh, form the selenosulfate ion, SeSO_3^{2-} , by reaction of elemental selenium with sulfite (WARREN, 1968), an intermediate product of sulfur redox reactions. Such a metastable selenium-sulfur ion might thus effect movement of selenium into the region of very low Eh within the ore deposit (GRANGER and WARREN, 1969).

Reduction of SeO_3^{2-} and formation of ferroselite continues until oxygen acceptors are consumed. Selenite ions can then be carried through the elemental selenium-ferric oxide and the ferroselite-ferric oxide zones, passing into the ore zone, a region of lower oxidation potential in which reduced forms of several metals have already been deposited and in which the active reducing agents H_2S and HS^- , produced either by biologically sterile dissociation of oxy-sulfur products (GRANGER and WARREN, 1969) or by bacterial sulfate reduction, are accumulating. Ferroselite forms in this zone in association with iron

sulfides and reduced uranium minerals. At very low oxidation potentials, selenium is incorporated into the iron-sulfide mineral structures, forming highly seleniferous pyrite or marcasite (COLEMAN and DELEVAUX, 1957).

Continued introduction of oxidizing ore solution oxidizes and mobilizes elemental selenium from the upflow side of the metal deposit and moves it into an environment of lower potential to be reduced and deposited. As the higher oxidation potentials encroach upon the deposit the following successions of oxidative reactions occur: elemental selenium to SeO_3^{2-} ; ferroselite to elemental selenium and, subsequently, to SeO_3^{2-} ; seleniferous pyrite to ferroselite and ferric oxides, then to elemental selenium, later to SeO_3^{2-} . Similarly, other minerals of the deposit are oxidized, moved, reduced, and deposited. Early mineral accumulations which are very low in tenor become, through successive activity of the oxidizing solution, deposits of much higher concentrations (GRUNER, 1956; KASHIRTEVA, 1964; GRANGER and WARREN, 1969). Selenium lags behind in the migration of other minerals of the ore body as it requires conditions more oxidizing to be dissolved and will be deposited as elemental selenium and ferroselite upon encountering a redox potential less reducing than that necessary to form pyrite and the uranium minerals.

Acknowledgements—My thanks and appreciation go to Prof. K. B. KRAUSKOPF, Stanford University, for his interest, encouragement, and guidance whenever necessary in my geochemical studies. I am also grateful for my reviewers' helpful criticism. Especially useful was reference to thermodynamic data for ferroselite (MILLS, 1975), supplied by C. G. WARREN; as a result the thermodynamic treatment now stands on much firmer ground, rather than on the hypothetical and assumed free-energy values of the first version (also in HOWARD, 1969). Funds from the Department of Geology and the School of Earth Sciences at Stanford University, which made the experimental and analytical work possible, are acknowledged with appreciation.

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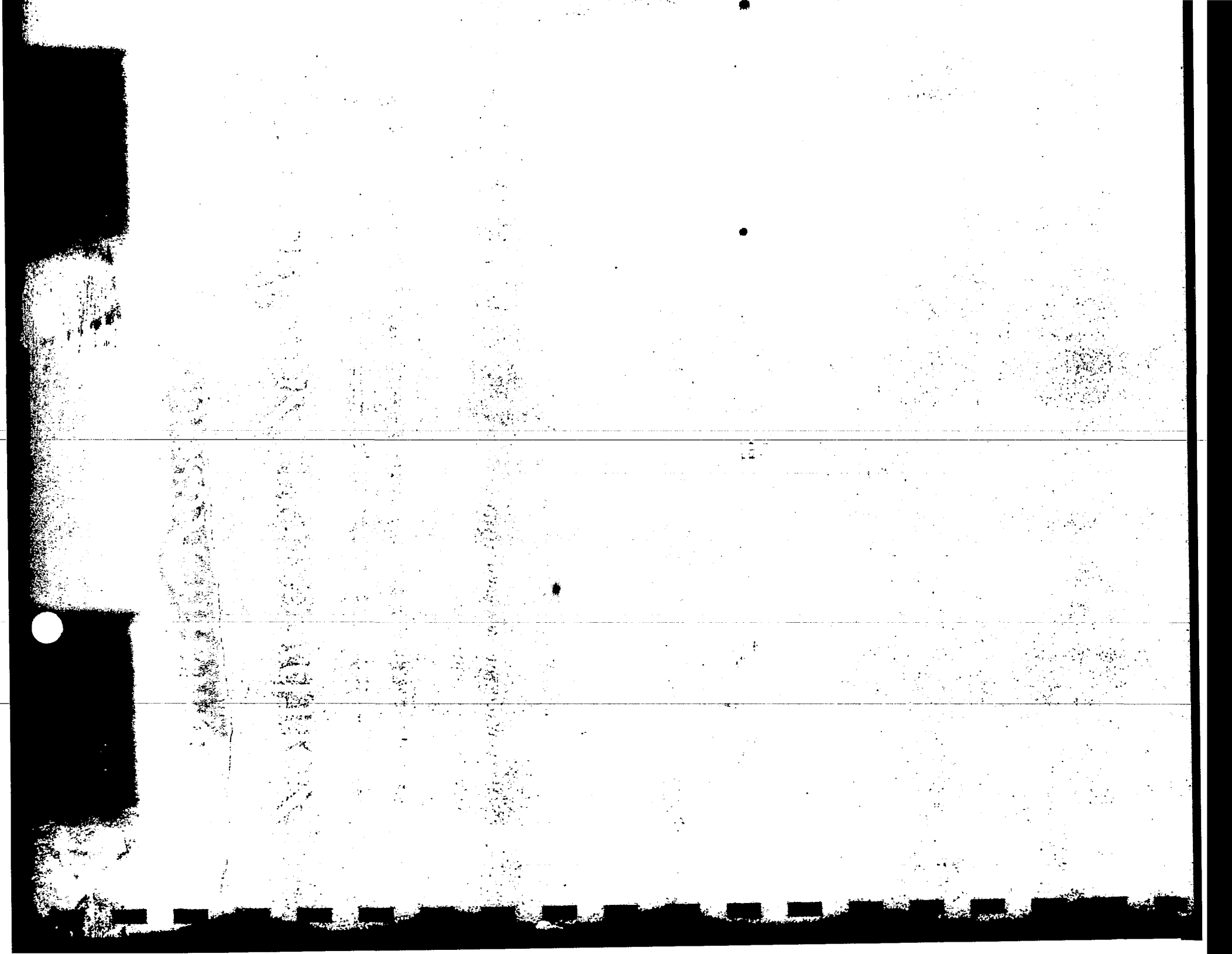
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Uranium Resources of Northwestern New Mexico

By LOWELL S. HILPERT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 603

*Prepared on behalf of the
U.S. Atomic Energy Commission*

*A description of the stratigraphic and structural
relations of the various types of uranium deposits
in one of the world's great uranium-producing
regions*



UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

URANIUM RESOURCES OF NORTHWESTERN NEW MEXICO

Uranium deposits, by county, in northwestern New Mexico

Location		T.	R.	Description of deposit and sample	
McKinley County—Continued					
Junior (4)-----	NE¼ 4-----	13 N.	10 W.	Mineralized zone in carbonaceous sandstone near base of Dakota Sandstone. Ore mined from open-cut, 1953.	FN, November 1954
Pat (Dakota) (84) -	SE¼NE¼ 4----- (about 300 ft from ¼ cor. secs. 3 and 4).	13 N.	10 W.	Several lenses of dark-gray radioactive material in zone about 15 ft thick in upper part of 60- to 80-ft-thick sandstone. This sandstone may be at base of Jmb or at top of Jmw. The lenses are in buff to gray crossbedded sandstone and range in thickness from a few inches to about 1 ft. In 1954, the workings were four short partly connected adits, all within an outcrop distance of about 100 ft. Mined in 1952-63 but most of ore mined since 1958.	Do.
Section 5 (Westvaco; Febco(?)) (8).	5-----	13 N.	10 W.	Probably in Dakota Sandstone, but some may occur in Jmb. Ore was mined from adit, 1958.	AEC.
Sections 10 and 11.	10 and 11-----	13 N.	10 W.	Mineralized material in sandstone in Jmb and possibly in Jmw.	AEC, DH.
Sections 12 and 13.	12 and 13-----	13 N.	10 W.	Mineralized material in sandstone in Jmb and possibly in Jmw. Locality is near western limit of Jmpe. Relations of the deposits to Jmpe are not known.	Do.
Section 14-----	NE¼ 14-----	13 N.	10 W.	Some mineralized sandstone and a few scattered mineralized fossil logs at outcrop, probably in Jmpe.	Mathewson (1953, p. 11).
Red Point Lode (28).	SW¼SW¼ NW¼ 16.	13 N.	10 W.	Small deposit in middle and lower parts of Todilto Limestone, associated with eastward-trending intraformational anticlinal fold in limestone. Deposit mined from open pit, 1952-55.	Gabelman (1956b, p. 394); McLaughlin (1963, p. 146).
Section 17-----	NW¼ 17-----	13 N.	10 W.	Several small deposits in Todilto Limestone-----	Food Machinery and Chemical Corp., DH, July 1955; and AEC, DH.
Do-----	NW¼NW¼ SW¼ 17.	13 N.	10 W.	Small deposit in Todilto Limestone-----	Do.
Section 18, NE¼---	S¼NE¼ 18-----	13 N.	10 W.	Northward extension of several medium deposits from SE¼ of section and several other scattered small deposits in Todilto Limestone.	AEC, DH.
Section 18, SW¼ (Williams and Thompson) (32).	SW¼ 18-----	13 N.	10 W.	Cluster of medium and small irregularly shaped deposits in Todilto Limestone. Several deposits mined from inclined shaft, others from opencuts, 1952-64.	Federal Uranium Corp., DH, June 1956; AEC
Section 18, SE¼ (Williams) (3).	SE¼ 18-----	13 N.	10 W.	Cluster of medium and small irregularly shaped deposits in Todilto Limestone. Deposits mined from open pits, 1953.	AEC, DH.
Haystack (Haystack Butte; Section 19, NW¼) (16).	NW¼ 19-----	13 N.	10 W.	Large, irregularly shaped, roughly tabular, partly oxidized deposit approximately in middle part of Todilto Limestone. Deposit is elongate northward and associated with numerous intraformational folds in limestone, some of which include the top few feet of the Entrada Sandstone. These folds have diverse trends, but the dominant trends are northward and eastward. Ore mined from open-cut, 1952-57.	FN, July 1955; Haystack Mountain and Development Co., DH, 1955; Gabelman (1956b, p. 393-396).
Section 19, NE¼ (34).	N¼N¼NE¼ 19--	13 N.	10 W.	Several small or medium deposits, near or at outcrop of Todilto Limestone. Deposits mined in 1959-64.	AEC.
Section 22, NE¼---	NE¼ 22-----	13 N.	10 W.	Small deposit in Todilto Limestone. Deposit worked by open pit, but no shipments reported.	McLaughlin (196 p. 146).
Section 23 (38)----	S¼SE¼ 23-----	13 N.	10 W.	Cluster of small and medium irregularly shaped deposits in middle and lower parts of Todilto Limestone. Cluster is in elongate zone about 300 ft wide that trends eastward along southern margin of SE¼ of section and into adjoining secs. 25 and 26. Ore mined from opencuts, 1957-58.	Haystack Mountain and Development Co., DH, June and January 195
Bob Cat (11)-----	NE¼NE¼(?) 24.	13 N.	10 W.	Deposit probably in Jmpe. Ore shipped in 1955-----	AEC.

high uranium content of the host rock is demonstrated by a suite of 10 samples collected between Abiquiu and Santa Fe (fig. 18). Uranium content of these samples ranged from 2 to 12 ppm (parts per million) and averaged >5 ppm. Eight of the samples were sandstone and two were siltstone. Although they were collected roughly parallel to the strike of the beds, they likely represent several hundred feet of stratigraphic section, including the part that contains the uranium deposits, because the coverage is about 40 miles.

The high uranium content of the Tesuque Formation can most likely be attributed to the high uranium concentrations in the volcanic ash, as shown by the following five samples:

Sample	Locality	Description	Uranium content (ppm)	
			U	eU ¹
2A ² -----	Center E $\frac{1}{4}$ sec. 33, T. 19 N., R. 9 E. (= 1 mile south of locality of sample 252605, fig. 18).	Top 3 in. of 42-in.-thick exposure of ash bed.	18.1	(³)
2B ² -----	do-----	28 in. above base of ash bed described for sample 2A.	10.7	(³)
2 ² -----	do-----	6 in. above base of ash bed described for sample 2A.	5.6	(³)
239584....	NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 17, T. 20 N., R. 9 E.	Channel across 4-ft-thick white tuff bed.	(³)	20
239585....	Center SW $\frac{1}{4}$ sec. 17, T. 20 N., R. 9 E. (= 3,500 ft north-east of locality of sample 252603, fig. 18, and 1,700 ft west of locality of sample 239584 (see above)).	do-----	(³)	30

¹ Analyst, C. G. Angelo.

² Data from R. L. Cannon (oral commun., 1965).

³ No data.

These samples show a range in content of 5.6–30 ppm U or eU and, although the eU values may be high because of disequilibrium, the tuffs probably average more than the entire host rock.

The uranium deposits postdate the Tesuque Formation. Their surficial relations and envelopment within radioactive opal, which also coats surficial debris, indicate that they were probably formed in the present cycle of weathering.

PENECONCORDANT DEPOSITS IN TODILTO LIMESTONE AND ADJACENT FORMATIONS

About 100 deposits or clusters of deposits are listed in the Todilto Limestone, of Jurassic age, on plate 1. Deposits occur in other limestone units, but are uncom-

associated with faults and are classified as vein deposits. A few others are segments of deposits that are primarily in sandstone; they have been described previously. Most of the deposits in the Todilto Limestone are in the Ambrosia Lake and Laguna districts, McKinley and Valencia Counties. A few are scattered in the southern part of the Chama Basin, Rio Arriba County, and in the Chuska district, San Juan County.

From 1950 to 1964, about 980,000 tons of ore was produced from 52 mines in the Todilto Limestone. This ore had an average grade of 0.22 percent U_3O_8 but ranged from 0.10 to 0.43 percent U_3O_8 among the mines. Prior to 1959, 445,000 tons of this ore averaged 0.14 percent V_2O_5 and had a U:V ratio of about 5:2, similar to that of most of the deposits in sandstone. All but a few thousand tons was mined in the Ambrosia Lake District; the remainder came from three mines in the Laguna district and one mine in Rio Arriba County.

The ores ranged from 25 to 98 percent lime and averaged 80 percent. Ores from only a few mines averaged less than 50 percent $CaCO_3$; these were mostly mixed ores that came from deposits that extended into the underlying Entrada Sandstone or overlying Summerville Formation, such as the Sandy, Zia, and Haystack 2.

STRATIGRAPHY

Regional stratigraphy of the Todilto Limestone and its relations to the underlying Entrada Sandstone and overlying Summerville Formation were outlined previously (p. 18), but the local stratigraphy in the Ambrosia Lake and Laguna districts will be discussed in more detail to explain the relationships of the deposits.

In the Ambrosia Lake district only the limestone member crops out, but the gypsum-anhydrite member has been penetrated by drill holes about 8 miles north of the outcrop (J. C. Wright, written commun., 1957). The limestone member, which contains all the deposits, ranges in thickness from about 5 to 30 feet and averages about 15 feet. It comprises three units which are referred to locally as the basal "platy," medial "crinkly," and the upper "massive" zones. The platy and crinkly zones are about equal in thickness and compose about half the total thickness of the member. They consist of fine-grained laminated and thin-bedded limestone, which contains thin siltstone partings and locally seams of gypsum. Black fine-grained films of carbon-rich material are conspicuous locally, especially along the partings in the crinkly unit. Bedding in the platy unit is undisturbed, but in the crinkly unit is intensely crenulated. The massive unit is more coarsely crystalline and indistinctly bedded limestone, and it varies markedly in thickness from place to place.

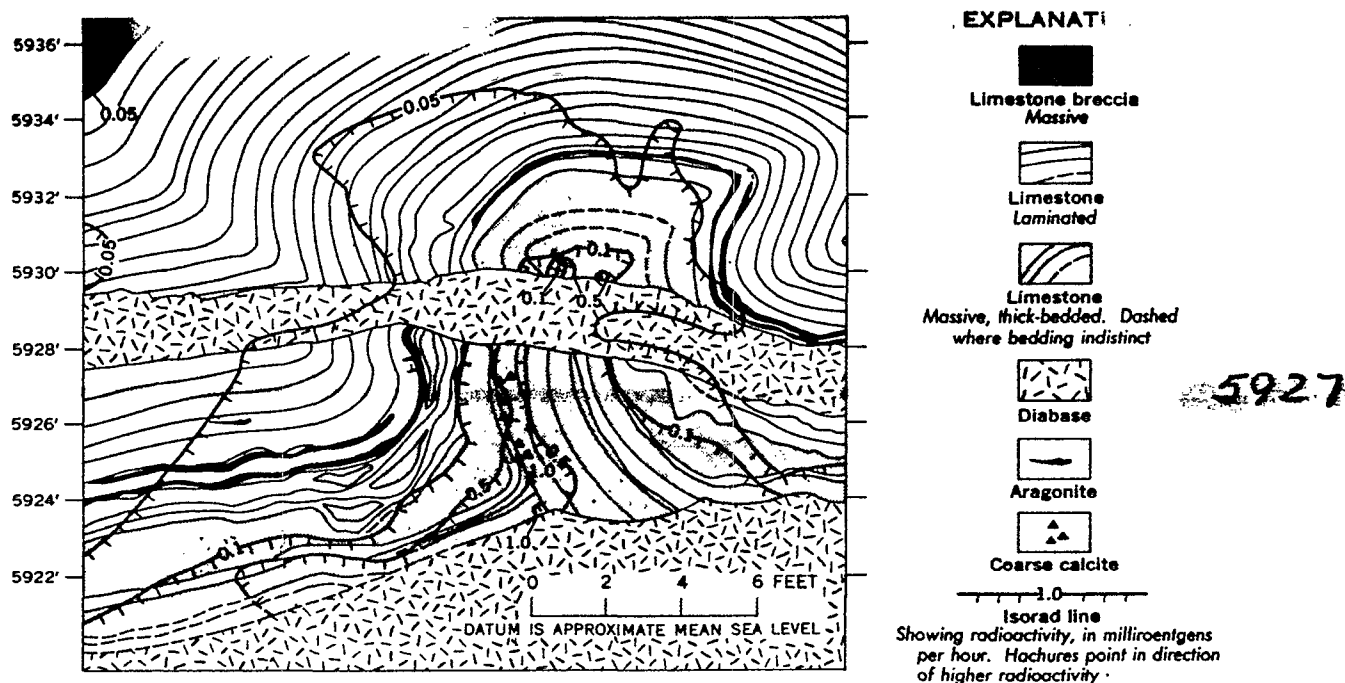


FIGURE 19.—Geologic section across uranium deposit in Todilto Limestone, showing displacement by diabase intrusive, Sandy mine area. Geology by Frank Hensley.

intersect deposits, the deposits are displaced and therefore must be older.

Gabelman (1956b, p. 391-392, fig. 132), however, implied that the deposits may be younger than the faults and folds by noting that the deposits occur within the area of strongest faulting and along the axes of northeastward-trending folds, both of which are on the flank of the Zuni uplift and within the sharpest bend of the strike of the Thoreau homocline (meaning the bend of the Chaco slope southeastward around the Zuni uplift and southward along the west flank of the McCartys syncline).

Gabelman's northeastward-trending folds probably are related to the subparallel faults (see p. 61), and both probably are the same age. Because the faults displace the deposits, both the folds and the faults must be younger than the deposits and could not have influenced their emplacement.

The oldest recognizable structural features that are certainly younger than the deposits are the fractures in the Laguna district that formed contemporaneously with the Rio Grande trough during the third period of deformation. These fractures are intruded by diabasic dikes and sills which, in turn, are broken by the same set of fractures, a relation that indicates their contemporaneity. The deposits show no relation to the fractures, and the diabasic intrusives displace and metamorphose the uranium deposits (Moench, 1962; 1963c, p.

161) (fig. 19). These facts demonstrate that the deposits are clearly older than the fractures and the intrusives.

Field relations indicate the fractures and intrusives probably formed mostly in middle to late Tertiary time, and probably prior to the Mount Taylor eruptions. Inclusions of the diabase were found in a volcanic pipe that probably supplied one of the earliest basaltic flows (Hilpert and Moench, 1960, p. 444). The fact that these flows were extruded during the latest stages of the Mount Taylor eruptions indicates the diabasic rocks are at least older than what may be the oldest basaltic flows. Because the entire sequence of Mount Taylor probably formed during an eruptive cycle, a relatively short period of time, the diabasic intrusions probably took place before the Mount Taylor cycle, as well as before the basaltic extrusions. Conclusions are that the deposits are older than any of the intrusive igneous rocks within the Laguna and Ambrosia Lake districts and that their emplacement could not have been influenced by them.

PENECONCORDANT DEPOSITS IN SHALE AND COAL

Deposits in shale and coal are quite similar in mineralogy and form to those in sandstone and, in some instances, where they occur in nearly equal proportions in both rock types, are classified rather arbitrarily. The host rocks, however, are different, so the deposits are separated for descriptive purposes. The deposits occur in shale and coal of Permian, Cretaceous, and Tertiary

Rapaport, Hadfield, and Olson (1952) described the intraformational folds and dated their formation as shortly after deposition of the Todilto. Gabelman (1956b) described some of them in detail and drew similar conclusions regarding the age of their formation, and Hilpert and Moench (1960) described their association and probable contemporaneity with the larger pre-Dakota folds in the Ambrosia Lake and Laguna districts.

The intraformational folds occur in a great variety of shapes, ranging from open and closed anticlines to recumbent folds, chevron folds, and fan folds. They are mostly anticlinal and asymmetric, but some are synclinal, open, and symmetrical. Most of the folds are small, pronounced structural features that have amplitudes generally less than their breadths. The largest have a breadth of as much as 50 feet and an amplitude of about 25 feet and involve the entire thickness of the Todilto and basal part of the overlying Summerville Formation. The smallest are measured in inches or fractions of an inch and commonly bear a drag relation to larger folds. In length the folds range from a few feet to hundreds of feet. They mostly are somewhat sinuous and elongate, but some are rather tortuous in plan or are simply domal.

The folds generally tend to be concentrated or clustered, and in both the Ambrosia Lake and Laguna districts the fold axes in the clusters generally trend eastward or northward. Others show an almost random arrangement.

All the folds are fractured or jointed and some are faulted. The associated faults, however, are almost invariably intraformational and die out within the folds or within the Todilto Limestone and basal part of the Summerville Formation. Many faults are reverse type and closely follow the axial plane of tight or recumbent folds. All the related faults, however, show little displacement, seldom more than a foot or so and generally not more than a few inches.

Most joints are nearly vertical and comprise many sets. The principal set is longitudinal to the folds and probably formed with the folds or shortly after, similar to the intraformational faults. Other subsidiary joints make up an almost random pattern, although in some deposits in the Ambrosia Lake district a minor set is roughly normal to the fold axes. Many of the joints probably formed during later periods of deformation. The complexity of the fold and fracture patterns is illustrated by the structures in the Haystack, Gay Eagle, and Black Hawk deposits (Gabelman, 1956b, figs. 135-137).

In the Laguna district the intraformational folds are localized along the flanks and troughs of broad east-

northward-trending pre-Dakota synclines, and the dominant trends of the axes of the intraformational folds are likewise eastward and northward (Moench, 1963c, p. 159). (See fig. 9, this report.)

The Todilto Limestone in the Laguna district is also somewhat thicker in the synclines than on the crests of the adjoining folds. This fact suggests that the intraformational folds formed by flowage down the limbs of the pre-Dakota folds. This flowage apparently occurred under cover in post-Todilto time because the intraformational folds are not truncated by bedding planes.

Similar relations are indicated in the Ambrosia Lake district. Where data are available, particularly where uranium deposits have been mined, the intraformational folds also tend to trend eastward and northward and to make up clusters with similar trends (Gabelman, 1956b, figs. 134-138; Hilpert and Moench, 1960, p. 460-461, fig. 18). The pre-Dakota folds in the overlying rocks likewise trend eastward; others might also trend northward, as in the Laguna district, but more detailed information is needed to determine this.

In the Chuska district small anticlinal intraformational folds occur along a 4-mile strip of outcrop west of Sanostee in the upper part of the Todilto. The largest folds have amplitudes of as much as 2 feet, a width of 3 feet, and a length of 15 feet. Where concentrated or most highly developed they are subparallel, but show no relation to Laramide structures (J. W. Blagbrough, D. A. Thieme, B. J. Archer, Jr., and R. W. Lott, written commun., 1959).

In the south part of the Chama Basin, similar intraformational folds have been noted in the Todilto Limestone at the outcrop south and east of Coyote. Some of these folds have amplitudes of as much as several feet and widths of as much as 25 or 30 feet, but their lengths and trends are not known.

Structural features that formed principally during the second period of deformation in the Ambrosia Lake district consist of the Chaco slope or homocline, west flank of the McCartys syncline, a set of fractures and folds that range in trend from northeast to north, and some domal and anticlinal structures. (See p. 61-62). In the Laguna district they consist of the east limb of the McCartys syncline, a north-trending faulted monocline, and a set of faults and fractures that were intruded in many places by diabasic dikes and sills. (See p. 72).

MINERALOGY AND FORM

Mineralogy of the uranium deposits in the Todilto Limestone has been partly described by Rapaport, Hadfield, and Olson, (1952, p. 9-12), Laverty and Gross (1956, p. 200), and Truesdell and Weeks (1960), and

has been summarized

by McLaughlin (1963, p. 140).

The deposits in the Todilto differ from the ones in sandstone principally in their relative sparseness of metallic sulfide minerals and in the occurrence of fluorite.

Unoxidized minerals that have been identified are ~~uraninite, coffinite, paramontroseite, haggite, fluorite, pyrite, marcasite, and galena~~. Barite, specular hematite, vanadium clay, and recrystallized calcite are closely associated with these minerals and probably are also primary.

~~Uraninite~~ is ~~more abundant~~ than ~~coffinite~~ and occurs as colloform coatings on grain boundaries, as veinlets in limestone, and as replacements of the limestone grains along bedding planes and along the walls of veinlets. Coffinite at least locally coats uraninite and fills shrinkage cracks in uraninite.

The formation of haggite, paramontroseite, and vanadium clay generally preceded that of uraninite. The haggite occurs as fine blades and fibers along grain boundaries and solution channels in limestone, and some as intergrowths with paramontroseite. The vanadium clay in some places forms irregular spherical aggregates.

~~Fluorite~~ has been ~~identified~~ in ~~general deposits~~ and likely is a ~~product~~ of most of them. It generally is purple and occurs as a fine-grained replacement of the limestone along bedding surfaces, as veinlets, and locally as irregular replacements of limestone that form masses as much as 6 inches in diameter. The fluorite generally is closely associated with and in places is replaced by uraninite.

Pyrite, marcasite, and galena are the only sulfide minerals identified in the deposits in the Todilto. Pyrite occurs as an early mineral which is generally corroded and replaced by later minerals but is most abundant as a late mineral which fills solution cavities and fractures and which replaces detrital grains. Marcasite has been identified only as a late mineral. Galena occurs as fine-grained cubes deposited with and after uraninite and coffinite and as a replacement of early pyrite and haggite.

Coarse-grained calcite occurs along bedding planes, fractures, and solution cavities as a replacement of limestone or as recrystallized limestone in and near the uranium deposits. The coarse-grained calcite is both earlier and later than most other minerals.

Fine-grained hematite occurs in most of the deposits and generally is associated with the uraniferous zones. Specular hematite has been noted with vanadium clay. Hematite also occurs as pseudomorphs after pyrite and

as stains along fractures and bedded zones.

Barite occurs in most deposits as a resinous yellow to clove-brown tabular mineral that lines solution cavities and forms veinlets or irregular globelike replacements of coarse-grained calcite or local disseminations along the bedding.

Most of the deposits in the Todilto occur at or near the surface and so have been subjected to oxidation which has led to the rather widespread occurrence of the conspicuous yellow and green secondary minerals tyuyamunite, metatyuyamunite, uranophane, and probably sklodowskite. Less common secondary minerals are carnotite, cuprosklodowskite, gummite, santafeite, liebigite, and various oxides of manganese and iron. Also, the dark-olive green fibrous vanadyl vanadate, grantsite, was identified in the F-33 mine (Weeks and others, 1961) and probably occurs in other deposits in the Todilto.

Early field-examination reports generally mentioned carnotite as a constituent of most deposits and created the impression that the mineral was one of the more common ones. Most of the reported occurrences, however, were probably ~~tyuyamunite~~, which is more likely to form in limestone in which calcium is in excess of sodium. Tyuyamunite and carnotite are both canary yellow and difficult to distinguish in the field.

~~Uranium deposits~~ in the ~~Todilto~~ are ~~roughly tabular bodies~~ having an irregular form similar to the forms of the deposits in sandstone. Most of them occur along the flanks of the folds and some along the fold axes roughly parallel to the bedding, but locally the deposits cut across the bedding. Many of them are near the base of the Todilto, but others are near the middle or top, and a few occupy the entire limestone interval. Many are not confined to the limestone, but extend a few inches and in some places several feet into the underlying Entrada Sandstone, and in many deposits as much as several feet into the overlying siltstone of the Summerville Formation. A few deposits are mostly, or entirely, in the basal part of the Summerville or top of the Entrada Sandstone. Although these deposits have a relationship to bedding that is similar to that of deposits in other sandstones, they are dissimilar in their association with folds in the overlying or underlying Todilto Limestone.

~~Dimensions of the deposits in the Todilto range from a few feet in width and length to several hundred feet in width and more than 1,000 feet in length, and in thickness from mere seems to as much as 20 feet. They probably average a few tens of feet in width, a hundred feet or so in length, and about 10 feet in thickness.~~

The largest deposits occur where the limestone are clustered and have a similar cause of the clustering, the deposits associated individual folds interconnect or merge into relatively large masses that in some places are rather irregular or oblong, such as the Haystack (Gabelman, 1956b, figs. 133, 135) and Flat Top 4-Vilatie Hyde deposits. Others merge and interconnect to form stringlike masses having a length many times their width, such as the F-33 (Hilpert and Moench, 1960, fig. 18), the Faith (McLaughlin, 1963, fig. 6), and the Section 25. The dominant trends of these masses are eastward or northward, similar to the trends of the intraformational folds, but many are heterogeneous.

Ore bodies generally constitute the central parts of the deposits where the deposits are thicker and higher in grade. Away from ore, the deposits feather out or grade into barren host rock along rather irregular or vaguely defined zones. Ore bodies range from masses with dimensions of only a few feet that contain several tons of ore to masses that are hundreds of feet wide, more than 1,000 feet long, and several feet thick, and contain as much as 100,000 tons of ore. Most ore bodies, however, average about 25 feet in width, 100 feet in length, and 5-7 feet in thickness, and contain about 1,000 tons of ore. McLaughlin's (1963, fig. 6) map of the Faith deposit is a good example of the general relations of ore to mineralized ground.

Grade of the ore ranges from 0.10 U_3O_8 to at least 10.0 percent U_3O_8 .

STRATIGRAPHIC RELATIONS OF THE DEPOSITS

Uranium deposits in the Todilto Limestone show no direct relation to the stratigraphy of the formation but possibly are indirectly related to the gypsum-anhydrite member and probably are indirectly related to the original thickness of the limestone member.

From place to place the deposits occur at the base, middle, top, or throughout the limestone member and, in many places, extend into the top of the underlying Entrada Sandstone or base of the overlying Summerville Formation. No known deposits occur in the gypsum-anhydrite member, but all the principal deposits are near its outcrop. (See pl. 3.) This position of the deposits in relation to the member probably stems from chance exposure, but for some unknown physical or chemical reason, the gypsum-anhydrite member may have influenced the emplacement of the deposits near its margin.

Near the principal deposits the limestone member is about 15-25 feet thick (pl. 3). Elsewhere it is generally less than 15 feet thick. This occurrence of deposits near thicker limestone may also be a result of

exposure—the Todilto Limestone has been exposed most only a few miles from the outcrop—probably it expresses some relation of the deposits to the original thickness of the limestone.

STRUCTURAL RELATIONS OF THE DEPOSITS

Primary uranium deposits in the Todilto were directly controlled by structures that resulted from the first period of deformation (Late Jurassic to Early Cretaceous), but show few effects, except secondary ones, from later deformation.

The deposits are closely related to intraformational folds in the limestone and these folds are related to broader open folds in the Jurassic rocks, which are dated as post-Todilto and pre-Dakota. The deposits are postsynthetic because they cross the limestone bedding (fig. 19), and are postintraformational folding because they transect the intraformational folds (Gabelman, 1956b, fig. 136, cross section L-K) and at least locally transect the broader pre-Dakota folds (Hilpert and Moench, 1960, p. 458, fig. 15; Moench, 1963c, p. 163-164).

The original thickness of the limestone (see above) probably had a direct bearing on the localization and development of the intraformational folds. Confinement of the folds largely within the limestone indicates its relative incompetence; it should follow that where the limestone is thickest it would have a tendency to absorb a greater percentage of the stresses exerted on the rock column. Thus, the degree of deformation expressed by the folds would most likely be a direct result of the original thickness of the limestone member. The deposits are directly related to the folds and generally to their degree or intensity of development: thus they are indirectly related to the original thickness of the limestone.

No convincing evidence supports the possibility that localization of the primary deposits was influenced by the second (Late Cretaceous to middle Tertiary) or third (middle Tertiary to late Tertiary or Quaternary) periods of deformation. Present information indicates that the oldest structural features resulting from these periods of deformation are the faults and folds that formed contemporaneously with the development of the McCartys syncline. As indicated above, the syncline and the associated smaller features probably formed during development of the Zuni and Lucero uplifts and the Ácoma sag, and probably prior to the northward tilting of the San Juan Basin (pre-San Jose, or pre-early Eocene time).

In the Ambrosia Lake district, deposits do not occupy fault zones except for the intraformational faults within the Todilto Limestone. Where faults

PENECONCORDANT DEPOSITS IN SHALE AND COAL

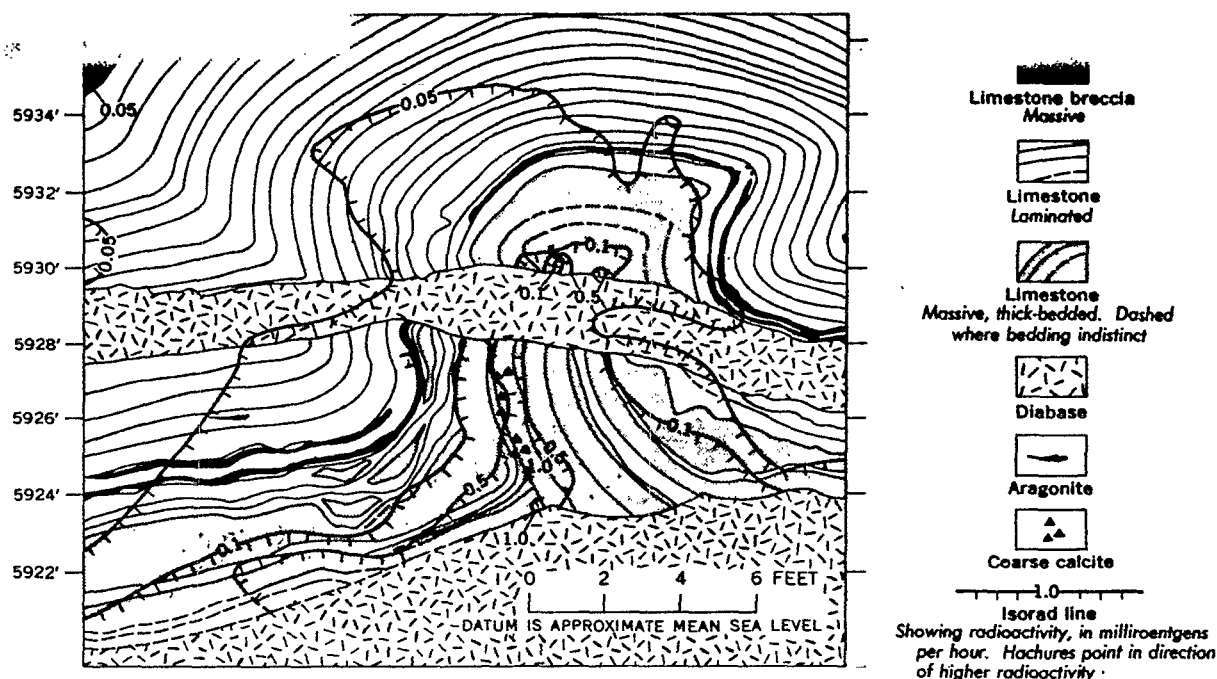


FIGURE 19.—Geologic section across uranium deposit in Todilto Limestone, showing displacement by diabase intrusive, Sandy mine area. Geology by Frank Hensley.

intersect deposits, the deposits are displaced and therefore must be older.

Gabelman (1956b, p. 391-392, fig. 132), however, implied that the deposits may be younger than the faults and folds by noting that the deposits occur within the area of strongest faulting and along the axes of northeastward-trending folds, both of which are on the flank of the Zuni uplift and within the sharpest bend of the strike of the Thoreau homocline (meaning the bend of the Chaco slope southeastward around the Zuni uplift and southward along the west flank of the McCartys syncline).

Gabelman's northeastward-trending folds probably are related to the subparallel faults (see p. 61), and both probably are the same age. Because the faults displace the deposits, both the folds and the faults must be younger than the deposits and could not have influenced their emplacement.

The oldest recognizable structural features that are certainly younger than the deposits are the fractures in the Laguna district that formed contemporaneously with the Rio Grande trough during the third period of deformation. These fractures are intruded by diabasic dikes and sills which, in turn, are broken by the same set of fractures, a relation that indicates their contemporaneity. The deposits show no relation to the fractures, and the diabasic intrusives displace and metamorphose the uranium deposits (Moench, 1962; 1963c, p.

161) (fig. 19). These facts demonstrate that the deposits are clearly older than the fractures and the intrusives.

Field relations indicate the fractures and intrusives probably formed mostly in middle to late Tertiary time, and probably prior to the Mount Taylor eruptions. Inclusions of the diabase were found in a volcanic pipe that probably supplied one of the earliest basaltic flows (Hilpert and Moench, 1960, p. 444). The fact that these flows were extruded during the latest stages of the Mount Taylor eruptions indicates the diabasic rocks are at least older than what may be the oldest basaltic flows. Because the entire sequence of Mount Taylor probably formed during an eruptive cycle, a relatively short period of time, the diabasic intrusions probably took place before the Mount Taylor cycle, as well as before the basaltic extrusions. Conclusions are that the deposits are older than any of the intrusive igneous rocks within the Laguna and Ambrosia Lake districts and that their emplacement could not have been influenced by them.

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Deposits in shale and coal are quite similar in mineralogy and form to those in sandstone and, in some instances, where they occur in nearly equal proportions in both rock types, are classified rather arbitrarily. The host rocks, however, are different, so the deposits are separated for descriptive purposes. The deposits occur in shale and coal of Permian, Cretaceous, and Tertiary

BLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*

erial within brackets is descriptive, not part of mine name. Italic numbers are mine numbers shown on plate 1. Spectrographic determinations are semiquantitative and were made by the rapid visual comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, 0.15, and are coded as follows: >10=f, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7; 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15. Figures reported as less than (<) are coded: <1.0=a, <0.05=b, <0.02=c, <0.005=d, <0.002=e, <0.001=f, <0.0005=g, <0.0002=h, <0.00005=i. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (.....), not looked for; number enclosed in parentheses is near threshold of detectability; ND, no data

[Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded]

Sample ¹	Name of mine or prospect	Spectrographic ²																	
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	
Ore in the Todilke Limestone																			
124.....	Barbara J 1 (1).....	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	
125.....	Billy The Kid (3).....	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	
126.....	Black Hawk (4).....	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	
127.....	Bunney (4).....	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	
130.....	Cedar 1 (5).....	i	5	0	0	b	9	0	0	1	0	b	(15)	12	ND	13	0		
128.....	Christmas Day (6).....	0	5	0	0	0	9	0	0	1	0	b	14	14	.....	13	0	
128.....	Crackpot (7).....	0	4	0	0	0	10	0	0	1	0	.....	0	13	.....	12	0	
129.....	Flat Top 4 (12).....	0	3	0	0	0	9	0	0	1	0	b	15	13	.....	13	0	
130.....	Gay Eagle (13).....	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	13	0	
132.....	Hanosh (Section 26) (15).....	i	4	0	0	b	9	0	0	1	0	b	(15)	13	ND	13	0		
132.....	Haystack 2 (17).....	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	12	0	
132.....	Last Chance (19).....	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	12	0	
133.....	Red Bluff 3 (24).....	0	5	0	0	0	9	0	0	1	0	b	14	15	.....	13	0	0
134.....	Red Bluff 5 (25).....	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	13	0	0
135.....	Red Bluff 7 (26).....	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
136.....	Red Bluff 8 (15).....	0	3	0	0	0	8	0	0	1	0	b	14	13	.....	12	0	0
131.....	Red Bluff 10 (13).....	i	4	0	0	b	9	0	0	1	0	b	(15)	14	ND	13	0	0	
137.....	Red Point Lode (28).....	0	5	0	0	0	8	0	0	1	0	b	15	14	.....	13	0	0
131.....	Reed Henderson.....	0	5	0	0	0	9	0	0	1	0	.....	0	13	.....	13	0	0
138.....	Rimrock (29).....	0	5	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
139.....	Section 18 (32).....	Tr.	3	0	0	0	7	0	0	1	0	b	14	13	.....	12	0	0
140.....	Section 18 (33).....	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	12	0	0
135.....	Section 19 (34).....	i	5	0	0	b	11	0	0	1	12	b	g	15	ND	13	0	0	
141.....	Section 21 (37).....	0	2	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
142.....	Section 24 (39).....	0	3	0	0	0	8	0	0	1	0	b	15	14	.....	12	0	0
132.....	Manol (Section 30) (22).....	i	4	0	0	b	10	0	0	1	0	b	(15)	12	ND	13	0	0	
143.....	Manol (Section 30, T-8) (22).....	0	4	0	0	0	9	0	0	1	0	b	15	13	.....	12	0	0
144.....	Manol (Section 30, T-19) (22).....	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
134.....	T 2 (45).....	i	5	0	0	b	10	0	0	1	(12)	b	g	14	ND	13	0	0	
145.....	Tom Elkins (48).....	0	2	0	0	0	7	0	0	1	0	b	15	14	.....	12	0	0
146.....	UDC 5 (49).....	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0

Ore in the Todilke Limestone and Estrada Sandstone

229.....	Sandy (76).....	0	3	0	0	Tr.	9	0	0	1	0	0	13	12	12	0	0
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IBUTION OF ELEMENTS IN THE ORES

BLE 6.—Semi-

Biometric, and chemical analyses of mill pulp samples of uran-
northwestern New Mexico

Material within brackets is descriptive, not part of mine name. Italic numbers are mine numbers shown on plate 1. Spectrographic determinations are semiquantitative and were made by the rapid visual comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, 0.15, and are coded as follows: >10=1, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7, 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15. Figures reported as less than (<) are coded: <1.0=a, <0.05=b, <0.02=c, <0.005=d, <0.002=e, <0.001=f, <0.0005=g, <0.0002=h, <0.00005=i. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (.....), not looked for; number enclosed in parentheses is near threshold of detectability; ND, no data

(Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded)

Sample ¹	Name of mine or prospect	Spectrographic ²																
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
Ore in the Tedlike Limestone																		
424	Barbara J 1 (1)	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
256425	Billy The Kid (3)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
256426	Black Hawk (4)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
256427	Bunney (4)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
430	Cedar 1 (5)	1	5	0	0	b	9	0	0	1	0	b	(15)	12	ND	13	0	0
428	Christmas Day (6)	0	5	0	0	0	9	0	0	1	0	b	14	14	.....	13	0	0
428	Crackpot (7)	0	4	0	0	0	10	0	0	1	0	.....	0	13	.....	12	0	0
429	Flat Top 4 (12)	0	3	0	0	0	9	0	0	1	0	b	15	13	.....	13	0	0
256430	Gay Eagle (13)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	13	0	0
223392	Hanosh (Section 25) (15)	1	4	0	0	b	9	0	0	1	0	b	(15)	13	ND	13	0	0
432	Last Chance (19)	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	12	0	0
432	Red Bluff 3 (21)	0	5	0	0	0	9	0	0	1	0	b	14	15	.....	13	0	0
434	Red Bluff 5 (25)	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	13	0	0
256435	Red Bluff 7 (26)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
256436	Red Bluff 8 (15)	0	3	0	0	0	8	0	0	1	0	b	14	13	.....	12	0	0
223391	Red Bluff 10 (15)	1	4	0	0	b	9	0	0	1	0	b	(15)	14	ND	13	0	0
437	Red Point Lode (28)	0	5	0	0	0	8	0	0	1	0	b	15	14	.....	13	0	0
437	Reed Henderson	0	5	0	0	0	9	0	0	1	0	.....	0	13	.....	13	0	0
436	Rimrock (29)	0	5	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
439	Section 18 (32)	Tr.	3	0	0	0	7	0	0	1	0	b	14	13	.....	12	0	0
256440	Section 18 (32)	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	12	0	0
223395	Section 19 (34)	1	5	0	0	b	11	0	0	1	12	b	g	15	ND	13	0	0
256441	Section 21 (37)	0	2	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
442	Section 24 (39)	0	3	0	0	0	8	0	0	1	0	b	15	14	.....	12	0	0
442	Manol (Section 30) (22)	1	4	0	0	b	10	0	0	1	0	b	(15)	12	ND	13	0	0
443	Manol (Section 30, T-5) (22)	0	4	0	0	0	9	0	0	1	0	b	15	13	.....	12	0	0
444	Manol (Section 30, T-19) (22)	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
223394	T 2 (45)	1	5	0	0	b	10	0	0	1	(12)	b	g	14	ND	13	0	0
256445	Tom Elkins (48)	0	2	0	0	0	7	0	0	1	0	b	15	14	.....	12	0	0
446	UDC 5 (49)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
Ore in the Tedlike Limestone and Estrada Sandstone																		
245229	Sandy (76)	0	3	0	0	Tr.	9	0	0	1	0	0	13	12	.....	12	0	0
Ore in the San Andres Limestone																		
245227	Lucky Don (1)	0	4	0	0	Tr.	11	0	0	1	0	0	13	12	.....	12	0	0
Ore in the Madera Limestone																		
254110	Agua Torres (1)	0	3	0	0	12	7	0	0	3	0	0	14	12	.....	11	0	0
254109	Marie (2)	14	3	5	0	12	8	0	0	2	0	0	12	11	.....	9	0	0

See footnotes at end of table.

TABLE 6.—Semiquantitative spectrographic.

of mill pulp samples of uranium ores from limestone, continued

Sample ¹	Name of mine or prospect	Spectrographic ² —Continued																
		Eu	F	Fe	Ga	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn
Ore in the Todilto Limestone																		
256424.....	Barbara J 1 (1).....	0	-----	6	0	0	0	0	0	0	0	0	4	0	0	0	6	2
256425.....	Billy The Kid (5).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256426.....	Black Hawk (4).....	0	-----	5	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256427.....	Bunney (4).....	0	-----	6	0	0	0	0	0	0	0	0	5	0	0	0	6	2
229390.....	Cedar 1 (5).....	ND	ND	5	h	0	0	0	0	ND	0	0	a	0	0	ND	6	2
256428.....	Christmas Day (6).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
245228.....	Crackpot (7).....	0	-----	6	0	0	0	0	0	0	0	0	4	0	0	-----	6	2
256429.....	Flat Top 4 (12).....	0	-----	6	0	0	0	0	0	0	0	0	5	0	0	0	6	2
256430.....	Gay Eagle (13).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
229393.....	Hanosh (Section 26) (15).....	ND	ND	6	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	2
256431.....	Harbuck 2 (17).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256432.....	Last Chance (19).....	0	-----	6	0	0	0	0	0	0	0	0	5	0	0	0	6	7
256433.....	Red Bluff 3 (24).....	0	-----	5	0	0	0	0	0	0	0	0	0	0	0	0	7	7
256434.....	Red Bluff 5 (25).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	7
256435.....	Red Bluff 7 (26).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256436.....	Red Bluff 8 (18).....	0	-----	6	0	0	0	0	0	0	0	0	5	0	0	0	6	2
229391.....	Red Bluff 10 (17).....	ND	ND	6	h	0	0	0	0	ND	0	0	a	0	0	ND	7	4
256437.....	Red Point Lode (28).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	5	2
245691.....	Reed Henderson.....	0	-----	7	0	0	0	0	0	0	0	0	4	0	0	-----	6	2
256438.....	Rimrock (29).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256439.....	Section 18 (32).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256440.....	Section 18 (33).....	0	-----	5	0	0	0	0	0	0	0	0	3	0	0	0	5	2
229395.....	Section 19 (34).....	ND	ND	7	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	6
256441.....	Section 21 (37).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256442.....	Section 24 (39).....	0	-----	6	0	0	0	0	0	0	0	0	4	0	0	0	6	2
229392.....	Manol (Section 30) (22).....	ND	ND	6	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	2
256443.....	Manol (Section 30, T-3) (22).....	0	-----	6	0	0	0	0	0	0	0	0	5	0	0	0	6	2
256444.....	Manol (Section 30, T-19) (22).....	0	-----	6	0	0	0	0	0	0	0	0	4	0	0	0	6	2
229394.....	T 2 (45).....	ND	ND	6	h	0	0	0	0	ND	0	0	a	0	0	ND	6	2
256445.....	Tom Elkins (45).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
256446.....	UDC 5 (49).....	0	-----	6	0	0	0	0	0	0	0	0	0	0	0	0	6	2
Ore in the Todilto Limestone and Entrada Sandstone																		
245229.....	Sandy (76).....			5	Tr.	0	0	0	0	0	0	0	3	0	0	-----	5	3
Ore in the San Andres Limestone																		
245227.....	Lucky Don (1).....			5	0	0	0	0	0	0	0	0	4	0	0	-----	2	
Ore in the Madera Limestone																		
254110.....	Agua Torres (1).....	0	-----	4	Tr.	0	0	0	0	0	0	0	4	0	0	0	5	3
254109.....	Marie (9).....	0	-----	2	14	0	0	0	0	0	0	0	3	0	0	0	6	9

See footnotes at end of table.

DISTRIBUTION OF ELEMENTS IN THE ORES

TABLE 6.

radiometric, and chemical analyses of mill pulp samples of
northwestern New Mexico—Continued

Sample ¹	Name of mine or prospect	Spectrographic ¹ —Continued																
		Mo	Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Se
Ore in the Todilke Limestone																		
256424	Barbara J 1 (1)	13	5	0	0	13	0	0	11	0	0	0	0	0	0	0	0	0
256425	Billy The Kid (3)	0	6	0	0	14	0	0	12	0	0	0	0	0	0	0	0	0
6426	Black Hawk (4)	14	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
6427	Bunney (4)	14	6	0	0	14	0	0	12	0	0	0	0	0	0	0	0	0
9390	Cedar 1 (6)	14	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	1
6428	Christmas Day (6)	14	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
245228	Crackpot (7)	0	6	0	0	14	0	0	12	0	0	0	0	0	0	0	0	0
256429	Flat Top 4 (12)	0	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
6430	Gay Eagle (13)	14	6	0	0	15	0	0	11	0	0	0	0	0	0	0	0	0
9393	Hanosh (Section 26) (16)	12	6	0	0	14	0	0	10	0	ND	0	ND	0	0	0	0	1
6431	Harriet (17)	0	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
6432	Last Chance (18)	0	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
256433	Red Bluff 3 (21)	13	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
256434	Red Bluff 5 (25)	12	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
256435	Red Bluff 7 (26)	0	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
6436	Red Bluff 8 (13)	14	6	0	0	13	0	0	11	0	0	0	0	0	0	0	0	0
9391	Red Bluff 10 (15)	13	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	1
6437	Red Point Lode (28)	0	6	0	0	15	0	0	12	0	0	0	0	0	0	0	0	0
9391	Reed Henderson	0	6	0	0	14	0	0	14	0	0	0	0	0	0	0	0	0
256438	Rimrock (29)	0	6	0	0	14	0	0	13	0	0	0	0	0	0	0	0	0
256439	Section 18 (32)	0	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
256440	Section 18 (33)	0	5	0	0	14	0	0	12	0	0	0	0	0	0	0	0	0
9395	Section 19 (34)	1	7	0	0	15	0	0	13	0	ND	0	ND	0	0	0	0	1
6441	Section 21 (37)	0	6	0	0	15	0	0	13	0	0	0	0	0	0	0	0	0
6442	Section 24 (39)	0	6	0	0	15	0	0	11	0	0	0	0	0	0	0	0	0
23992	Manol (Section 30) (23)	1	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	1
256443	Manol (Section 30, T-8) (22)	0	6	0	0	13	0	0	11	0	0	0	0	0	0	0	0	0
256444	Manol (Section 30, T-19) (22)	14	6	0	0	13	0	0	10	0	0	0	0	0	0	0	0	0
23994	T 2 (45)	1	7	0	0	14	0	0	13	0	ND	0	ND	0	0	0	0	1
56445	Tom Elkins (48)	0	6	0	0	14	0	0	12	0	0	0	0	0	0	0	0	0
56446	UDC 5 (49)	13	6	0	0	14	0	0	11	0	0	0	0	0	0	0	0	0
Ore in the Todilke Limestone and Entrada Sandstone																		
45229	Sandy (76)	13	4	0	0	14	0	0	12	0	0	0	0	0	0	0	0	0
Ore in the San Andres Limestone																		
45227	Lucky Don (1)	13	6	0	0	11	0	0	11	0	0	0	0	0	0	0	0	0
Ore in the Madera Limestone																		
54110	Agua Torres (1)	12	7	0	0	12	0	0	12	0	0	0	0	0	0	0	0	14
54109	Marie (2)	10	6	0	0	12	0	0	5	0	0	0	0	0	0	0	10	14

See footnotes at end of table.

TABLE 6.—Semi-quantitative spectrogr.

alyses of mill pulp samples of uranium ores from limestone.
—Continued

Sample ¹	Name of mine or locality	Spectrographic ² —Continued															
		Li	Tb	Te	Th	Ti	Tm	U	V	W	Y	Yb	Zn	Zr			
Ore in the Todilko Limestone																	
256424	Barbara J 1 (1)	1	0	0	0	0	0	0	6	9	0	0	14	d	0	0	0
256425	Billy The Kid (3)	1	0	0	0	0	0	0	0	7	9	0	0	0	0	0	0
256426	Black Hawk (4)	2	0	0	0	0	0	0	0	8	9	0	0	0	0	0	0
256427	Runney (4)	2	0	0	0	0	0	0	0	8	9	0	0	0	0	0	0
256428	Cedar 1 (5)	2	0	10	0	0	0	0	0	ND	8	0	0	0	0	0	0
256429	Christmas Day (6)	3	0	0	0	0	0	0	0	0	8	7	0	0	0	0	0
256430	Crackpot (7)	3	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0
256431	Flat Top 4 (12)	2	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256432	Gay Eagle (13)	2	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256433	Hancock (Section 26) (15)	7	0	10	0	0	0	0	0	ND	6	8	0	14	0	0	0
256434	Last Chance (16)	2	0	0	0	0	0	0	0	0	8	9	0	0	0	0	0
256435	Reb Bluff 3 (24)	2	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
256436	Reb Bluff 5 (25)	2	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
256437	Reb Bluff 7 (26)	2	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
256438	Reb Bluff 8 (27)	1	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256439	Reb Bluff 10 (28)	2	0	10	0	0	0	0	0	ND	7	8	0	0	0	0	0
256440	Red Point Lode (28)	2	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256441	Reed Henderson	2	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
256442	Rimrock (29)	2	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
256443	Section 18 (31)	1	0	0	0	0	0	0	0	0	8	7	0	0	0	0	0
256444	Section 18 (32)	1	0	0	0	0	0	0	0	0	8	0	0	14	0	0	0
256445	Section 19 (33)	4	0	10	0	0	0	0	0	ND	7	7	0	0	0	0	0
256446	Section 21 (37)	3	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
256447	Section 24 (39)	1	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256448	Manoli (Section 30) (42)	1	0	0	0	0	0	0	0	ND	6	7	0	0	0	0	0
256449	Manoli (Section 30, T-3) (42)	1	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256450	Manoli (Section 30, T-10) (42)	1	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0
256451	T-2 (42)	3	0	10	0	0	0	0	0	ND	6	7	0	0	0	0	0
256452	Tom Atkins (43)	3	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
256453	UDC 5 (44)	2	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
Ore in the Todilko Limestone and Entrada Sandstone																	
245229	Sandy (76)	1	0	10	0	0	0	0	0	0	8	0	13	15	0	0	11
Ore in the San Andres Limestone																	
245227	Lucky Don (1)	1	0	11	0	0	0	0	0	0	8	0	0	0	0	7	11
Ore in the Madera Limestone																	
254110	Agua Torres (1)	1	0	7	0	0	0	0	0	0	7	0	0	13	15	9	1
254109	Marie (3)	1	0	9	0	0	0	0	0	0	6	10	0	13	15	7	1

See footnotes at end of table.

DISTRIBUTION OF ELEMENTS IN THE ORES

TABLE

phic, radiometric, and chemical analyses of mill pulp samples
northwestern New Mexico—Continued

Sample ¹	Name of mine or prospect	Radio-metric				Chemical					
		U ²	U ³	V ₂ O ₅ ⁴	S ⁵	P ₂ O ₅ ⁷	C ⁶ (organic)	As ⁸	Fe ⁹	Se ¹⁰	Zn ¹¹
		Percent						Parts per million			
Ore in the Todilto Limestone											
254424	Barbara J 1 (1)	0.23	0.23	0.09	0.07	0.026	0.11	16	80	5	26
254425	Billy The Kid (3)	.09	.09	.30	.08	.003	.08	3	50	1	10
254426	Black Hawk (4)	.12	.12	.06	.04	.015	.07	23	240	3	16
254427	Bunney (4)	.06	.06	.11	.03	.003	.06	11	20	2	10
229390	Cedar 1 (6)	.21	.24			.024		60	280	5	20
254428	Christmas Day (6)	.16	.16	.13	.04	.003	.10	18	290	4	10
45228	Crackpot (7)	.07	.10	.22	.11	.011		18	100	3	7
254429	Flat Top 4 (12)	.19	.20	.13	.03	.003	.06	18	630	3	10
254430	Gay Eagle (13)	.16	.18	.15	.03	.003	.06	20	190	4	10
229393	Hanosh (Section 26) (16)	.31	.34			.031		50	1,700	5	20
254431	Haystack 2 (17) (24)	.15	.16	.15	.06	.015	.14	3	40	3	10
254432	Last Chance (19)	.12	.13	.23	.03	.003	.06	6	20	2	10
254433	Red Bluff 3 (24)	.17	.16	.06	.04	.015	.06	33	90	4	10
254434	Red Bluff 5 (25)	.16	.16	.05	.03	.018	.06	21	90	3	10
254435	Red Bluff 7 (26)	.13	.13	.09	.04	.003	.07	12	120	2	10
254436	Red Bluff 8 (15)	.13	.14	.14	.03	.003	.06	19	150	2	10
229391	Red Bluff 10 (18)	.17	.18			.017		60	440	5	10
254437	Red Point Lode (28)	.11	.11	.07	.03	.006	.06	20	30	3	10
46891	Reed Henderson	.03	.03	.12	.06	.015	.02	8	80	5	4
254438	Rimrock (29)	.10	.11	.28	.03	.003	.06	8	110	3	10
254439	Section 18 (32)	.15	.16	.33	.03	.003	.06	9	20	5	20
254440	Section 18 (33)	.10	.10	.23	.03	.003	.07	8	20	4	10
229395	Section 19 (34)	.14	.14			.004		10	100	5	10
254441	Section 21 (37)	.10	.11	.30	.03	.003	.06	2	20	2	10
254442	Section 24 (39)	.19	.18	.15	.03	.003	.06	2	20	1	20
29392	Manol (Section 30) (22)	.19	.23			.019		50	460	2	10
254443	Manol (Section 30, T-8) (22)	.17	.19	.11	.04	.007	.12	19	240	3	10
254444	Manol (Section 30, T-19) (22)	.28	.31	.07	.04	.029	.10	16	130	3	10
229394	T 2 (45)	.12	.13			.004		10	130	1	20
254445	Tom Elkins (48)	.12	.11	.19	.04	.003	.06	4	20	3	10
254446	UDC 5 (49)	.14	.14	.06	.04	.011	.06	29	370	5	10
Ore in the Todilto Limestone Limestone and Entrada Sandstone											
245220	Sandy (76)	0.09	0.10	0.13	0.06	0.024		15	90	15	12
Ore in the San Andres Limestone											
245227	Lucky Don (1)	0.17	0.22	0.43	0.06	0.011		41	240	10	830
Ore in the Madera Limestone											
254110	Agua Torres (1)	0.06	0.08	0.11	0.46			172		50	37
254109	Marie (8)	.17	.17	.06	3.27			6,200	800	75	2,100

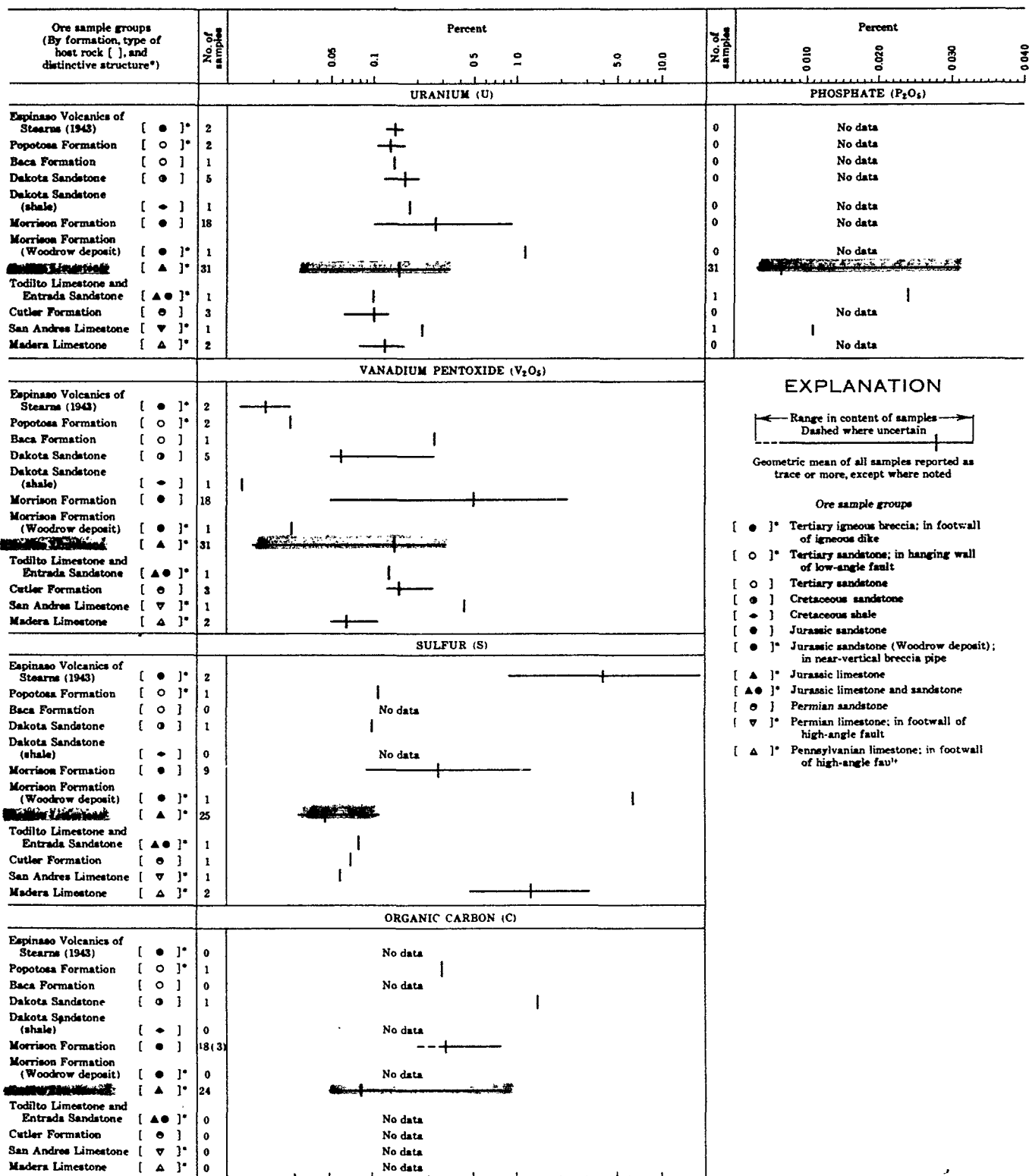
¹ Spectrographic analyses, chemical analyses for As, Se, U, and Zn, and radiometric analyses for U for samples 229390-229395 inclusive requested by A. T. Miesch.² Analysis of sample 246891 by N. M. Conklin; all others by R. G. Havens.³ Analysts: C. G. Angelo, R. P. Cox, G. S. Erickson, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg.⁴ Analysts: C. G. Angelo, R. P. Cox, E. J. Fennelly, D. L. Ferguson, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg. Fluorimetric method.⁵ Analysts: W. D. Goss, H. H. Lipp, and J. S. Wahlberg. Volumetric method.⁶ Analysts: G. T. Burrow, D. L. Ferguson, and E. C. Mallory. Gravimetric method.⁷ Analysts: D. L. Ferguson and L. F. Rader, Jr. Volumetric method.⁸ Analysts: Wayne Mountjoy and J. P. Schuch. Rapid scanning, CO₂ method.⁹ Analysts: R. R. Beins, H. E. Crowe, E. J. Fennelly, Claude Huffman, J. P. Schuch, and J. E. Wilson. Colorimetric method.¹⁰ Analysts: R. P. Cox, W. D. Goss, and L. F. Rader, Jr. Colorimetric method.¹¹ Analysts: C. G. Angelo, G. T. Burrow, R. P. Cox, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg. Colorimetric method.¹² Analysts: R. R. Beins, G. T. Burrow, and H. E. Crowe. Colorimetric method.

Ore sample groups (By formation, type of host rock [], and distinctive structure*)	No. of samples	Percent	No. of samples	Percent
		0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5		0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5
		NICKEL (Ni)		YTTRIUM (Y)
Espinazo Volcanics of Stearns (1943) [●]*	2		2	
Popotosa Formation [○]*	2		2	
Baca Formation [○]	1		1	
Dakota Sandstone [●]	5		5	
Dakota Sandstone (shale) [+]	1		1	
Morrison Formation [●]	18		18 (2)	
Morrison Formation (Woodrow deposit) [●]*	1		1	
Morrison Limestone [▲]*	31		1031(26)	
Todilto Limestone and Entrada Sandstone [▲●]*	1		1	
Cutler Formation [●]	3		3	
San Andres Limestone [▽]*	1		1 (1)	
Madera Limestone [▲]*	2		2	
		LEAD (Pb)		YTTERBIUM (Yb)
Espinazo Volcanics of Stearns (1943) [●]*	2		2	
Popotosa Formation [○]*	2		2 (1)	
Baca Formation [○]	1		1 (1)	
Dakota Sandstone [●]	5 (2)		5 (5)	
Dakota Sandstone (shale) [+]	1		1	
Morrison Formation [●]	18		17(17)	
Morrison Formation (Woodrow deposit) [●]*	1		1 (1)	
Morrison Limestone [▲]*	31		30(30)	
Todilto Limestone and Entrada Sandstone [▲●]*	1		1	
Cutler Formation [●]	3		3 (2)	
San Andres Limestone [▽]*	1		1 (1)	
Madera Limestone [▲]*	2		2	
		SCANDIUM (Sc)		ZIRCONIUM (Zr)
Espinazo Volcanics of Stearns (1943) [●]*	2		2	
Popotosa Formation [○]*	2		2	
Baca Formation [○]	1		1	
Dakota Sandstone [●]	5 (3)		5	
Dakota Sandstone (shale) [+]	1		1	
Morrison Formation [●]	18(12)		18	
Morrison Formation (Woodrow deposit) [●]*	1		1	
Morrison Limestone [▲]*	31(31)		31	
Todilto Limestone and Entrada Sandstone [▲●]*	1 (1)		1	
Cutler Formation [●]	3		3	
San Andres Limestone [▽]*	1 (1)		1	
Madera Limestone [▲]*	2		2	
		STRONTIUM (Sr)		
Espinazo Volcanics of Stearns (1943) [●]*	2			
Popotosa Formation [○]*	2			
Baca Formation [○]	1			
Dakota Sandstone [●]	5			
Dakota Sandstone (shale) [+]	1			
Morrison Formation [●]	18			
Morrison Formation (Woodrow deposit) [●]*	1			
Morrison Limestone [▲]*	31			
Todilto Limestone and Entrada Sandstone [▲●]*	1			
Cutler Formation [●]	3			
San Andres Limestone [▽]*	1			
Madera Limestone [▲]*	2			

¹⁰ Includes 2 samples reported as trace and assumed to be 0.001.

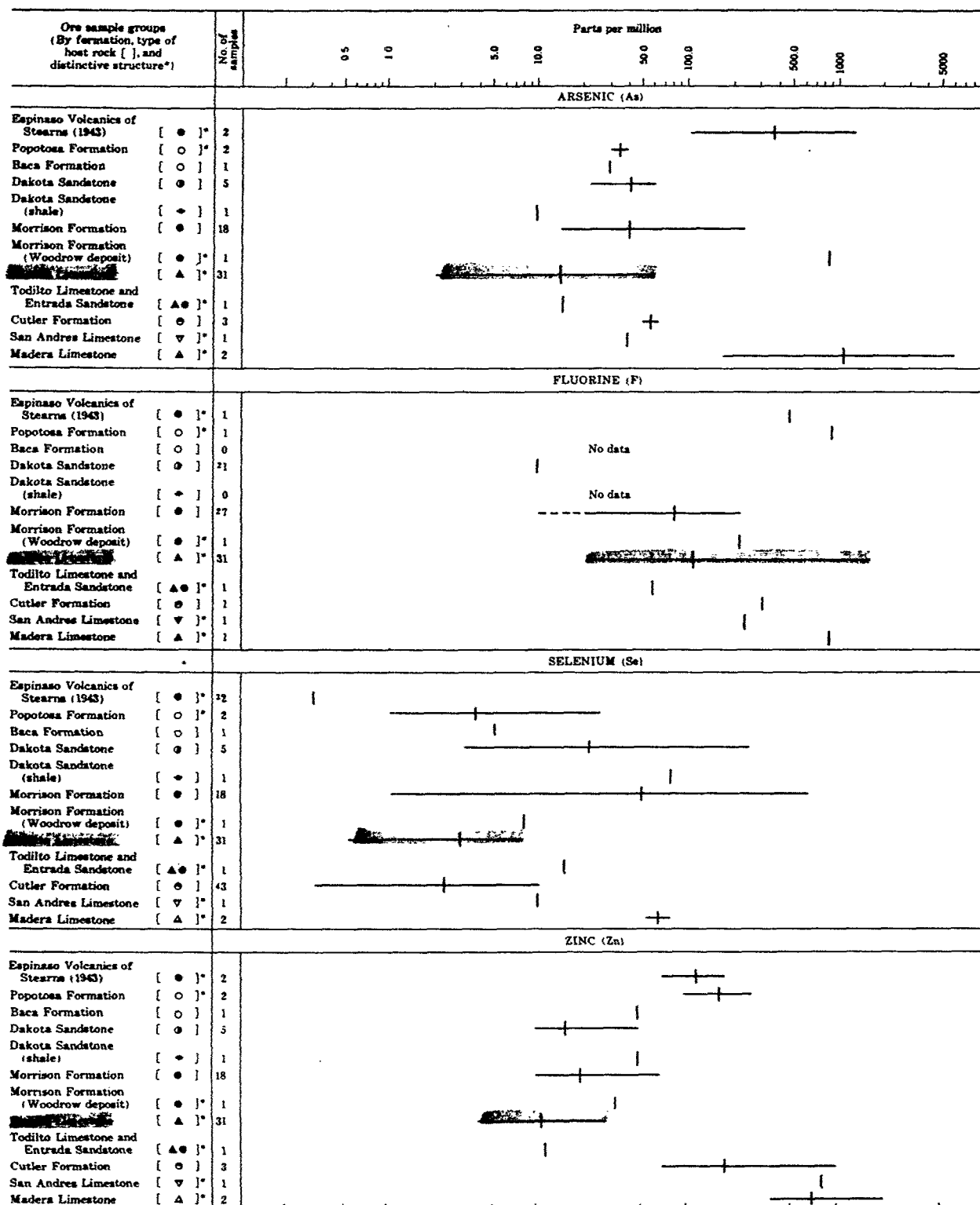
TABLE 9.—Ranges of concentration of carbon, arsenic, fluorine, selenium, vanadium pentoxide, sulfur, phosphate, organic

of the uranium ores, northwestern New Mexico

[Analyses are chemical except for some samples in which no chemical analyses are available or show an assay of <0.10 percent V_2O_5 ; spectrographic analyses are used by conversion of V to V_2O_5 .]

*Number in parentheses is samples below limit of detection, each reported as <0.3 and assumed to be 0.2 ppm.

Concentration and the geometric means of uranium, vanadium, niobium, and zinc in 12 sample groups of the uranium ores, northwestern Colorado, continued



*One sample reported as <20, assumed to be 10 ppm.

†Both samples reported as <0.5, assumed to be 0.3 ppm.

‡One sample reported as <0.5, assumed to be 0.3 ppm.

TABLE
[0, looked for but not found;

elements in the ore sample groups of classes 1 and 2
looked for; ~, approximately; not shown. Analyses are in percent, except
indicated]

Ore sample groups (by no.)				Cr	Cu	Fe	Mo	Ni	Pb	U	V ₂ O ₅	S	As	Parts per million		
Groups of class 1																
Baca Formation	0.0003	3	0.0003	0.0015	0.003	1.5	0.0007	0.0015	0.003	0.14	0.27		30		5	50
Dakota Sandstone	0	2.6	0.005	0.01	0.04	7	0.015	0.01	<.0007	.16	.04	0.10	40	~10	21	16
Dakota Sandstone (shale)	0	7	0.007	0.03	0.08	7	0.015	0.015	0.015	.18	.01		10		75	50
Morrison Formation	0	4.3	0.008	0.02	0.04	1.4	0.05	0.015	0.06	.26	.50		40	53	43	20
Redondo Limestone	<.00006	1.6	0.004	0.01	0.02	3	<.0011	0.007	0.05	.14	.14		15	23	23	11
Todilto Limestone and Entrada Sandstone	0	3	0.015	0.03	0.03	7	0.009	0.007	0.03	.10	.13	.08	15	60	15	12
Cutler Formation	~.0003	~9	.002	.004	.09	2.4	<.0014	.002	.025	.10	.15	.07	55	370	2.3	183
Groups of class 2																
Espinosa Volcanics of Stearns (1943) ¹	0.0003	4.6	0.02	0.015	1.5	4.6	0.005	0.09	0.0015	0.14	0.02	4.0	360	490	<.5	118
Popotosa Formation	<.000015	15	.005	.003	.05	2.1	.003	.005	.015	.13	.03	.11	35	920	3.7	167
Morrison Formation (Woodrow) deposit ²	0.003	3	.015	.0015	.015	7	.003	.007	.03	1.16	.03	6.6	890	220	8	35
San Andres Limestone	0	1.5	0.015	.003	.003	7.7	0.015	.007	.007	.22	.43	.06	41	240	10	830
Madera Limestone ³	~.0004	3	.0015	.0046	.014	3.2	.007	.003	.05	.12	.06	1.2	1.033	890	61	703

¹ This sample group also contains 0.03 Ce, 0.015 La, ~0.01 Nd, and 0.12 Sr; 1 sample contains 0.003 Ge.

² This sample group also contains a trace of Tl.

³ One sample in this sample group also contains 0.015 Sb and 0.015 Tl.

MORRISON FORMATION

Most data were obtained for the ore sample group of the Morrison Formation, the most important ore group in the area, from the standpoint of ore production and mine reserves. With the exception of some redistributed deposits in the Ambrosia Lake district and possibly the Gallup district, this ore group shows no direct relation to tectonic structures and, with the exception of the ores in the Salt Wash Member, no stratigraphic or geographic differences.

In general, the ore group in the Morrison shows a somewhat greater range in content of many elements than most other groups of class 1. This is principally the result of the greater number of samples, as indicated by the similar geometric means for the respective elements among the several sample groups (tables 7-9). An exception is vanadium, which has a relatively wide range and an average content that is much greater than that of any of the other groups. (See vanadium pentoxide, table 9.) These differences are reflected mostly by sample 254040 (table 5), which was taken from the northwestern part of the area where ores in the Salt Wash Member have an average U:V ratio of 1:7 (See table 2, Shiprock district.) Because the Salt Wash has a rather limited distribution in northwestern New Mexico, the ores that have a high vanadium content are restricted geographically as well as stratigraphically.

MORRISON FORMATION (WOODROW DEPOSIT)

The Woodrow deposit in the Morrison Formation differs from the groups in class 1 in its high content of 10 elements, the presence of coarse-grained coffinite in the ore, and the close association of the deposit with a faulted pipelike structural feature. These dif-

ferences justify assignment of the Woodrow deposit to class 2.

The contents of each of the following nine elements in the Woodrow deposit are greater than the highest respective contents of the sample groups in class 1 by the following multiples: silver, >6×; cobalt, 7½×; copper, 3½×; iron, 3×; nickel, 3½×; lead, 5×; uranium, 4½×; sulfur, 22×; and arsenic, 16×. The contents of lead and copper in the Woodrow are about the same or less than in the group in the Cutler Formation, which contains an appreciably higher content of these and some other elements than the groups in class 1. This matter is discussed below under Cutler Formation. The Woodrow also contains a trace of thallium, which is rarely detected in deposits of the peneconcordant type, and it also has a relatively high sulfide mineral content, which is expressed in the ore principally as pyrite and marcasite; this content is indicated by the high amounts of iron and sulfur (table 10). Conversely, the Woodrow is low in vanadium.

The mineralogy of the Woodrow deposit is similar to that of the group in the Morrison Formation, with two exceptions: one is its relatively high sulfide mineral content, and the other is the presence of coarse-grained coffinite (Hilpert and Moench, 1960, p. 446) which occurs only in a fine-grained or earthy form in other deposits in the Morrison Formation as well as in all other peneconcordant deposits. Thus, the significant differences between the Woodrow deposit and groups of class 1 are the high grade of the deposit, the presence of coarse-grained coffinite in the ore, and the association of the deposit with a faulted pipelike structural feature.

Fe Group (Miocene to Pleistocene?).—Several deposits are known in the Fe Group, but they generally are small and superficial. The resource outlook, however, is considered to range from poor at the outcrop to good in the subsurface, similar to the Galisteo and Popotosa Formations. The Santa Fe Group is widely exposed, but in most places only the upper few hundred feet of the sequence is represented; elsewhere the beds are covered by alluvium and surficial debris. Little, if any, exploration has been done for deposits in the unexposed beds. The great extent and thickness of these beds, and the favorableness of many of them for containing uranium deposits, offer a good potential for deposits that may range in size from small to large.

Older volcanic rocks of Jemez Mountains, Espinazo Volcanics of Stearns (1943), Cieneguilla Limburgite of Stearns (1953), and intrusive rocks of varied composition and form.—One medium-sized vein deposit occurs in the Espinazo Volcanics of Stearns (1943) on the eastern side of the Los Cerrillos district; a few other scattered small deposits, which are mostly surficial accumulations, occur in various types of intrusive and extrusive igneous rocks, mainly along the Rio Grande trough. The uranium resources in these rocks are small and the outlook is poor for finding more than a few small, or possibly medium-sized, deposits in them. The best potential is in the Los Cerrillos and Ortiz mining districts, where some uraniferous vein deposits might be found in association with the base-metal deposits.

AREAS RECOMMENDED FOR EXPLORATION

The principal uranium resources in northwestern New Mexico are in peneconcordant deposits, mostly in sandstone, partly in limestone, and to some extent in carbonaceous shale and coal. Most of these resources are along the margins of sedimentary basins, the most important of these areas being the southern and western parts of the San Juan Basin.

Of greatest importance is the southern part of the basin. On the basis of the frequency of distribution of the known deposits and their geologic relations, the deposits in this area are restricted to a zone or belt north of the outcrop of the Jurassic rocks which is at least 20 miles wide and which has been referred to as the southern San Juan Basin mineral belt (Hilpert and Moench, 1960). The northern limit of the belt is adjusted here to include the known areas of most intensive structural deformation during Late Jurassic time. This deformation is recognized as the prime control on the uranium deposits in the Morrison Formation and Todilto Limestone. As drawn, the northern limit of the belt extends from near the

ile sandstone northwest-
ucted boundary of the
to the outcrop of the

Morrison Formation on the western side of the San Juan Basin (fig. 20). Included in the belt are the Jackpile trough in the Laguna district (roughly marked by the Jackpile sandstone) and the main ore-bearing sandstone mass in the Ambrosia Lake district (areas C and D, respectively, fig. 20). Other structurally deformed areas probably occur in the western part of the belt and along its north margin. Certainly such areas will not be expected to end abruptly where the north margin is indicated. The boundary is drawn to show approximately where the deformation became less intensive northward.

Included in the belt is the part of the limestone unit of the Todilto Limestone that is 15 feet or more thick. This part includes almost all the mine reserves, has yielded almost all the ore, and probably contains most of the uranium resources in the Todilto. Where the limestone unit of the Todilto was thickest, it probably received the most intensive deformation and thus is considered most favorable for deposits. The Todilto generally lies about 400–500 feet below the base of the Morrison Formation. Because of this general depth and the smaller deposits in it, the Todilto is not of immediate economic interest except where it is not deeply buried.

The mineral belt also contains the most favorable ground for uranium deposits in the Dakota Sandstone, although the Jurassic deformation probably had little, if any, influence on them. The best ground is in the western part of the belt, where channel-type sandstone lenses are largest and thickest. This area is near the margin of the Dakota basin of deposition. Depths to the base of the Dakota will generally be about 500 feet nearer the surface than the base of the Morrison. Although the size of the deposits in the Dakota is about the same as the size of the ones in the Todilto, the deposits in the Dakota are more amenable to exploration and development, which can be coordinated with exploration for the deeper but generally larger deposits in the Morrison Formation.

In the western part of the San Juan Basin substantial resources may also be found in the Shiprock district in the Salt Wash Member of the Morrison Formation and in the Chuska district in the Recapture Member of the Morrison (fig. 20, areas A and B, respectively). Each of these areas defines the thickest part of the respective members where they apparently occupy eastward-trending structural depressions. Deposits in these rocks are expected to range from small to medium in size, similar to the ones at the

REFERENCE #35

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

Dangerous Properties of Industrial Materials

Seventh Edition

Volume III

N. IRVING SAX

and

RICHARD J. LEWIS, SR.



VAN NOSTRAND REINHOLD
NEW YORK

SYNS:

2,4-DIHYDROXYPYRIMIDINE
2,4-DIOXOPYRIMIDINE
HYBAR X
PIROD
2,4-PYRIMIDINEDIOL

2,4-PYRIMIDINEDIONE
2,4(1H,3H)-PYRIMIDINEDIONE
(9CI)
PYROD

TOXICITY DATA:

pic-esc 1 g/L
cyt-mus-ipr 15 ng/kg
ori-rat TDLo: 18 g/kg (17-22D
preg/21D post): REP
ori-rat TDLo: 616 mg/kg (7-17D
preg): REP
ori-rat TDLo: 378 g/kg/30W-C:
ETA
ipr-mus LD50: 1513 mg/kg

CODEN:

ZAPOAK 12,583,72
NULSAK 19,40,76
OYYAA2 22,109,81
OYYAA2 22,85,81
CNREA8 46,2062,86
JPETAB 207,504,78

EPA Genetic Toxicology Program. Reported in EPA TSCA Inventory.

THR: Moderately toxic by intraperitoneal route. An experimental tumorigen. Experimental reproductive effects. Mutagenic data. When heated to decomposition it emits toxic fumes of NO_x.

UNJ810

HR: 3

URACIL mixture with TEGAFUR (4:1)

CAS: 74578-38-4

NIOSH: YR 0480000

mf: C₈H₉FN₂O₃•4C₄H₄N₂O₂

mw: 648.59

SYNS:

FT mixture with URACIL (1:4)
TEGAFUR mixture with URACIL
(1:4)
1-(2-TETRAHYDROFURYL)-5-
FLUOROURACIL mixture with
URACIL (1:4)

UFT
URACIL mixture with FT (4:1)
URACIL mixture with 1-(2-TETRA-
HYDROFURYL)-5-FLUORO-
URACIL (4:1)

TOXICITY DATA:

ori-rat TDLo: 713 mg/kg (7-17D
preg): TER
ori-rat TDLo: 891 mg/kg (7-17D
preg): REP
ori-rat TDLo: 2503 mg/kg (7-22D
preg/21D post): TER
ori-rat LD50: 1580 mg/kg
ori-mus LD50: 1275 mg/kg
ori-dog LD50: 150 mg/kg
ori-rbt LD50: 242 mg/kg

CODEN:

OYYAA2 22,85,81
OYYAA2 22,85,81
OYYAA2 22,109,81
OYYAA2 20,1009,80
OYYAA2 20,1009,80
OYYAA2 20,1009,80
OYYAA2 20,1009,80

THR: Poison by ingestion. An experimental teratogen. Experimental reproductive effects. When heated to decomposition it emits toxic fumes of F⁻ and NO_x. See also URACIL.

UNS000

HR: 3

URANIUM

CAS: 7440-61-1

NIOSH: YR 3490000

DOT: 2979

af: U aw: 238.00

PROP: A heavy, silvery-white, malleable, ductile, softer-than-steel, metallic element. Mp: 1132°, bp: 3818°, d: 18.95 (ca). Radioactive material.

SYN: URANIUM METAL, PYROPHORIC (DOT)

Reported in EPA TSCA Inventory.

OSHA PEL: TWA 0.25 mg(U)/m³ACGIH TLV: TWA 0.2 mg(U)/m³; STEL 0.6 mg(U)/m³DFG MAK: 0.25 mg/m³

DOT Classification: Radioactive Material; Label: Radioactive and Flammable

THR: A highly toxic element on an acute basis. The permissible levels for soluble compounds are based on chemical toxicity, while the permissible body level for insoluble compounds is based on radiotoxicity. The high chemical toxicity of uranium and its salts is largely shown in kidney damage which may not be reversible. Acute arterial lesions may occur after acute exposures. The most soluble uranium compounds are UF₆, UO₂(NO₃)₂, UO₂Cl₂, UO₂F₂, and uranyl acetates, sulfates, and carbonates. Some moderately soluble compounds are UF₄, UO₂, UO₄, (NH₄)₂U₂O₇, UO₃, and uranyl nitrates. The rapid passage of soluble uranium compounds through the body tends to allow relatively large amounts to be taken in. Soluble uranium compounds may be absorbed through the skin. The least soluble compounds are high-fired UO₂, U₃O₈, and uranium hydrides and carbides. The high toxicity effect of insoluble compounds is largely due to lung irradiation by inhaled particles. This material is transferred from the lungs of animals quite slowly.

A very dangerous fire hazard in the form of a solid or dust when exposed to heat or flame. It can react violently with air; Cl₂; F₂; HNO₃; NO; Se; S; water; NH₃; BrF₃; trichloroethylene; nitryl fluoride. During storage it may form a pyrophoric surface due to effects of air and moisture. Depleted uranium (the ²³⁸U-by-product of the uranium enrichment process, with relatively low radioactivity) is used in armor-piercing shells, ship or aircraft ballast, and counterbalances. Uranium is also used in making colored ceramic glazes.

UOA000

HR: 3

URANIUM AZIDE PENTACHLORIDE

CAS: 55042-15-4

mf: Cl₅N₃U mw: 457.32

THR: A radioactive material. An explosive. When heated to decomposition it emits very toxic fumes of Cl⁻ and NO_x. See also URANIUM and AZIDES.

UOB100

HR: 3

URANIUM CARBIDE

CAS: 12070-09-6

mf: UC mw: 250.04

THR: A radioactive material. The powdered carbide ignites spontaneously in air. See also URANIUM.

SYNS:

BETAMETHASONE VALERATE
BETAMETHASONE 17-VALERATE
BETNOVATE
BETNOVATEAT
CELESTODERM

9-FLUORO-11- β ,17,21-TRIHY-
DROXY-16- β -METHYLPREGNA-
1,4-DIENE-3,20,DIONE-17-
VALERATE
 β -METHASONE-17-VALERATE

TOXICITY DATA:

skn-rat TDLo:42 mg/kg (35D
male):REP
skn-rat TDLo:19800 μ g/kg
(7-17D preg):TER
scu-mus TDLo:1 mg/kg (11D
preg):TER
scu-rat LDLo:2000 mg/kg
orl-mus LD50:4067 mg/kg
ipr-mus LD50:632
scu-mus LD50:496 mg/kg
scu-rbt LD50:61200 μ g/kg

CODEN:

OYYAA2 27,1217,84
YACHDS 9,3045,81
YKRYAH 10,1585,77
ARZNAD 27,2102,77
SKIZAB 29,153,73
SKIZAB 29,153,73
SKIZAB 29,153,73
OYYAA2 28,687,84

THR: Poison by subcutaneous route. Moderately toxic by intraperitoneal route. Mildly toxic by ingestion. An experimental teratogen. Experimental reproductive effects. When heated to decomposition it emits toxic fumes of F⁻.

VCK000**VALONEA TANNIN****HR: 3**

NIOSH: YW 0305000

SYNS:

QUERCUS AEGILOPS L. TANNIN

TANNIN from VALONEA

TOXICITY DATA:

scu-rat TDLo:750 mg/kg/2W-I:
CAR
ipr-mus LD50:110 mg/kg
scu-mus LD50:170 mg/kg
ivn-mus LD50:50 mg/kg
ims-mus LD50:280 mg/kg

CODEN:

BJCAAI 14,147,60
JPPMAB 9,98,57
JPPMAB 9,98,57
JPPMAB 9,98,57
JPPMAB 9,98,57

THR: Poison by intraperitoneal, intravenous, subcutaneous and intramuscular routes. An experimental carcinogen. See also TANNIC ACID.

VCP000**VANADIUM****HR: 3**

CAS: 7440-62-2

NIOSH: YW 1355000

af: V aw: 50.94

PROP: A bright, white, soft, ductile metal; sltly radioactive.
Bp: 3000°, d: 6.11 @ 18.7°, mp: 1917°. Insol in water.

TOXICITY DATA:

ims-rat TDLo:340 mg/kg/43W-I:
ETA
scu-rbt LD50:59 mg/kg

CODEN:

NCIUS* PH 43-64-
886,SEPT,71
FATOAO 28,83,65

Reported in EPA TSCA Inventory.

NIOSH REL: TWA 1.0 mg(V)/m³

THR: Poison by subcutaneous route. An experimental tumorigen. Flammable in dust form from heat, flame or

sparks. Violent reaction with BrF₃; Cl₂; lithium; nitryl fluoride; oxidants. When heated to decomposition it emits toxic fumes of VO_x. See also VANADIUM COMPOUNDS.

VCU000**HR: 3****VANADIUM AZIDE TETRACHLORIDE**mf: Cl₄N₃V mw: 234.76

Community Right To Know List.

THR: Explosive. When heated to decomposition it emits very toxic fumes of VO_x, Cl⁻ and NO_x. See also VANADIUM COMPOUNDS, AZIDES, and CHLORIDES.

VCZ000**HR: D****VANADIUM COMPOUNDS**

THR: Variable toxicity. Vanadium compounds act chiefly as an irritant to the conjunctivae and respiratory tract. Acute and chronic exposure can give rise to conjunctivitis, rhinitis, reversible irritation of the respiratory tract, and to bronchitis, bronchospasms, and asthma-like diseases in more severe cases. There is still some controversy as to the effects of industrial exposure on other systems of the body. Responses are mostly acute, seldom chronic. The first report of human vanadium poisoning described rather widespread systemic effects, consisting of polycythemia, followed by red blood cell destruction and anemia, loss of appetite, pallor and emaciation, albuminuria and hematuria, gastrointestinal disorders, nervous complaints and cough, sometimes severe enough to cause hemoptysis. More recent reports describe symptoms which, for the most part, are restricted to the conjunctivae and respiratory system, no evidence being found of disturbances of the gastrointestinal tract, kidneys, blood or central nervous system. Vanadate (VO₃⁻) is a potent inhibitor of the sodium pump, an enzyme universally present in eukaryotic organisms. The absorption of V₂O₅ by inhalation is nearly 100%. Though certain workers believe that it is only the pentoxide which is harmful, other investigators have found that patronite dust (chiefly vanadium sulfide) is quite toxic to animals, causing acute pulmonary edema. Acute poisoning in animals by ingestion of vanadium compounds causes nervous disturbances, paralysis of legs, respiratory failure, convulsions, bloody diarrhea, and death. Poisoning by inhalation causes bleeding of the nose and acute bronchitis. Some compounds have mutagenic effects. VF₅ and the oxyhalogenides of pentavalent vanadium (VOF₃, VOCl₃, VOBr₃) are volatile. Vanadium compounds are common air contaminants. The fumes are highly toxic. The major use of vanadium and its alloys is in the steel industry. When heated to decomposition it emits toxic fumes of VO_x. See also specific compounds.

VDA000**HR: 3****VANADIUM DICHLORIDE**

CAS: 10580-52-6

NIOSH: YW 1575000

mf: Cl₂V mw: 121.84

PROP: Hexagonal, green, deliquescent plates. D: 3.23 @ 18°. Sol in abs alc, glacial acetic acid.

TOXICITY DATA: CODEN:
orl-rat LD50: 540 mg/kg AIHAAP 30,470,69

NIOSH REL: CL 0.05 mg(V)/m³/15M

THR: Moderately toxic by ingestion. Will react with water or steam to produce toxic and corrosive fumes and explosive hydrogen gas. Platinum accelerates the reaction to violence. When heated to decomposition it emits toxic fumes of VO_x. See also HYDROCHLORIC ACID, VANADIUM COMPOUNDS, and CHLORIDES.

VDF000
VANADIUM ORE

HR: 2

NIOSH: YW 1630000

TOXICITY DATA: CODEN:
ihl-hmn TDLo: 4 µg/kg: PUL AMIHAB 12,635,55

NIOSH REL: (Vanadium Compounds) CL 0.05 mg(V)/m³/15M

THR: Human systemic effects by inhalation: pulmonary system effects. When heated to decomposition it emits toxic fumes of VO_x. See also VANADIUM COMPOUNDS.

VDK000
VANADIUM OXIDE TRIISOBUTOXIDE

HR: 3

CAS: 19120-62-8 NIOSH: YW 1115000
mf: C₁₂H₂₇O₄V mw: 287.14

SYNS:

ISOBUTYL ORTHOVANADATE	TRIISOBUTYL VANADATE
TRIISOBUTOXYOXOVANADIUM	TRIISOPROPOXYVANADIUM OX-
TRIISOBUTYL ORTHOVANADATE	IDE

TOXICITY DATA:	CODEN:
skn-rbt 500 mg/24H SEV	PESTC* 9,5,80
eye-rbt 100 mg SEV	PESTC* 9,5,80
orl-rat LD50: 293 mg/kg	PESTC* 9,5,80
skn-rbt LD50: 1930 mg/kg	PESTC* 9,5,80

THR: Poison by ingestion. Moderately toxic by skin contact. A severe skin and eye irritant. When heated to decomposition it emits acid smoke and irritating fumes of VO_x. See also VANADIUM COMPOUNDS.

VDP000
VANADIUM OXYTRICHLORIDE

HR: 3

CAS: 7727-18-6 NIOSH: YW 2975000
DOT: 2443

mf: Cl₃OV mw: 173.29

PROP: Yellow, deliquescent liquid. Mp: -77° ± 2°, bp: 126.7°, d: 1.811 @ 32°.

SYNS:

TRICHLOROXYOXOVANADIUM	VANADYL TRICHLORIDE
VANADIUM TRICHLORIDE OXIDE	

TOXICITY DATA:
orl-rat LD50: 140 mg/kg

CODEN:
AIHAAP 30,470,69

Reported in EPA TSCA Inventory.

ACGIH TLV: TWA 0.05 mg(V₂O₅)/m³
NIOSH REL: (Vanadium Compounds) CL 0.05 mg(V)/m³/15M

DOT Classification: Corrosive Material; Label: Corrosive

THR: Poison by ingestion. A corrosive irritant to skin, eyes and mucous membranes. Explosive reaction with sodium. Violently hygroscopic. Violent reaction with rubidium (at 60°C); potassium. When heated to decomposition it emits toxic fumes of VO_x and Cl⁻. See also VANADIUM COMPOUNDS and HYDROCHLORIC ACID. For further information, see Vol. 2, No. 2 of *DPIM Report*.

VDU000

HR: 3

VANADIUM PENTOXIDE (dust)

CAS: 1314-62-1 NIOSH: YW 2450000
DOT: 2862

mf: O₅V₂ mw: 181.88

PROP: Yellow to red, crystalline powder. Mp: 690°, bp: decomp @ 1750°, d: 3.357 @ 18°.

SYNS:

ANHYDRIDE VANADIQUE (FRENCH) C.I. 77938 RCRA WASTE NUMBER P120 VANADIC ANHYDRIDE VANADIO. PENTOSSIDO di (ITAL- IAN) VANADIUM DUST and FUME (ACGIH) VANADIUM OXIDE (V ₂ O ₅)	VANADIUM(V) OXIDE VANADIUM PENTAOXIDE VANADIUM PENTOXIDE, non-fused form (DOT) VANADIUM, PENTOXIDE de (FRENCH) VANADIUMPENTOXID (GERMAN) VANADIUMPENTOXIDE (DUTCH) WANADU PIECIOTLENEK (POL- ISH)
---	--

TOXICITY DATA:
mrc-bcs 500 mmol/L
ivn-mus TDLo: 10900 mg/kg (8D
preg): TER
ihl-hmn TCLo: 346 mg/m³: PUL
ihl-hmn TCLo: 1 mg/m³/8H:
PUL,EYE
orl-rat LD50: 10 mg/kg
ihl-rat LCLo: 70 mg/m³/2H
ipr-rat LD50: 12 mg/kg
scu-rat LD50: 14 mg/kg
itr-rat LDLo: 25 mg/kg
orl-mus LD50: 23 mg/kg
scu-mus LD50: 10 mg/kg
ihl-cat LCLo: 500 mg/m³/23M
scu-rbt LDLo: 20 mg/kg
ivn-rbt LDLo: 10 mg/kg
scu-gpg LDLo: 20 mg/kg

CODEN:
MUREAV 77,109,80
ENVRAL 33,47,84

AMIHAB 19,497,59
AEHLAU 14,709,67

ATXKA8 16,182,56
NTIS** AEC-TR-6710
ATXKA8 16,182,56
ATXKA8 16,182,56
NTIS** AEC-TR-6710
85GMAT -,119,82
ZVKOA6 19,186,74
30ZIAO -,140,64
27ZWAY 3.3,1541,-
27ZWAY 3.3,1541,-
30ZIAO -,140,64

Reported in EPA TSCA Inventory. EPA Genetic Toxicology Program.

OSHA PEL: CL 0.5 mg/m³
ACGIH TLV: TWA 0.05 mg(V₂O₅)/m³

DFG MAK: (fine dust) 0.05 mg/m³

NIOSH REL: (Vanadium Compounds) CL 0.05 mg(V)/m³/15M

DOT Classification: ORM-E; Label: None; Poison B; Label: Poison

THR: Poison by ingestion, inhalation, intraperitoneal, subcutaneous, intratracheal and intravenous routes. An experimental teratogen. Human systemic effects by inhalation: bronchiolar constriction, including asthma, cough, dyspnea, sputum, and conjunctiva irritation. Experimental reproductive effects. Mutagenic data. A respiratory irritant; causes skin pallor, greenish-black tongue, chest pain, cough, dyspnea, palpitation, lung changes. When ingested it causes gastrointestinal tract disturbances. May also cause a papular skin rash. Mixtures with calcium + sulfur + water may ignite spontaneously. The absorption of V₂O₅ by inhalation is nearly 100%. Incompatible with ClF₃; Li; peroxyformic acid. When heated to decomposition it emits acrid smoke and irritating fumes of VO_x. See also VANADIUM COMPOUNDS. For further information, see Vol. 2, No. 2 of *DPIM Report*.

VDZ000

HR: 3

VANADIUM PENTOXIDE (fume)

CAS: 1314-62-1

NIOSH: YW 2460000

mf: O₅V₂ mw: 181.88

SYN: VANADIUM DUST AND FUME (ACGIH)

EPA Extremely Hazardous Substances List. Reported in EPA TSCA Inventory. EPA Genetic Toxicology Program.

OSHA PEL: CL 0.1 mg/m³

ACGIH TLV: TWA 0.05 mgg(V₂O₅)/m³

NIOSH REL: (Vanadium Compound) CL 0.05 mg(V)/m³/15M

THR: A poison by several routes. Can react violently with (Ca + S + H₂O); ClF₃; Li. When heated to decomposition it emits toxic fumes of VO_x. See also VANADIUM PENTOXIDE (DUST). For further information, see Vol. 2, No. 2 of *DPIM Report*.

VEA000

HR: 3

VANADIUM SESQUIOXIDE

CAS: 1314-34-7

NIOSH: YW 3050000

mf: O₃V₂ mw: 149.88

PROP: Black crystals. Mp: 1970°, d: 4.87 @ 18°.

SYNS:

VANADIC OXIDE

VANADIUM TRIOXIDE

VANADIUM OXIDE

TOXICITY DATA:

itr-rat LDLo: 125 mg/kg

orl-mus LD50: 382 mg/kg

scu-mus LD50: 130 mg/kg

CODEN:

NTIS** AEC-TR-6710

GTPZAB 8,25,64

ZVKOA6 19,186,74

Reported in EPA TSCA Inventory.

NIOSH REL: CL 0.05 mg(V)/m³/15M

THR: Poison by ingestion, subcutaneous and intratracheal routes. Ignites when heated in air. When heated to decomposition it emits toxic fumes of VO_x. See also VANADIUM COMPOUNDS.

VEF000

HR: 3

VANADIUM TETRACHLORIDE

CAS: 7632-51-1

NIOSH: YW 2625000

DOT: 2444

mf: Cl₄V mw: 192.74

PROP: Reddish-brown liquid. Mp: -28 ± 2°, bp: 148.5°, d: 1.816 @ 30°.

SYN: VANADIUM CHLORIDE

TOXICITY DATA:

orl-rat LD50: 160 mg/kg

CODEN:

AIHAAP 30,470,69

Reported in EPA TSCA Inventory.

ACGIH TLV: TWA 0.05 mg(V₂O₅)/m³

NIOSH REL: (Vanadium Compound) CL 0.05 mg(V)/m³/15M

DOT Classification: Corrosive Material; Label: Corrosive

THR: Poison by ingestion. A corrosive irritant to skin, eyes and mucous membranes. When heated to decomposition it emits toxic fumes of VO_x and Cl⁻. See also VANADIUM COMPOUNDS and HYDROCHLORIC ACID.

VEK000

HR: 3

VANADIUM TRIBROMIDE

CAS: 13470-26-3

NIOSH: YW 2750000

mf: Br₃V mw: 290.67

PROP: Green-black, deliquescent crystals. Mp: decomp.

SYN: VANADIUM BROMIDE

TOXICITY DATA:

scu-rbt LDLo: 20 mg/kg

CODEN:

27ZWAY 3,3,1541,-

Reported in EPA TSCA Inventory.

NIOSH REL: CL 0.05 mg(V)/m³/15M

THR: Poison by subcutaneous route. When heated to decomposition it emits toxic fumes of VO_x and Br⁻. See also VANADIUM COMPOUNDS and BROMIDES.

VEK100

HR: 3

VANADIUM TRIBROMIDE OXIDE

CAS: 13520-90-6

mf: Br₃OV mw: 306.65

THR: Reacts violently with water. When heated to decomposition it emits toxic fumes of Br⁻ and VO_x. See also

REFERENCE #36

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

**TOXICOLOGICAL PROFILE FOR
ARSENIC**

Date Published — March 1989

Prepared by:

Life Systems, Inc.
under Contract No. 68-02-4228

for

Agency for Toxic Substances and Disease Registry (ATSDR)
U.S. Public Health Service

in collaboration with

U.S. Environmental Protection Agency (EPA)

Technical editing/document preparation by:

Oak Ridge National Laboratory
under
DOE Interagency Agreement No. 1857-B026-A1

6. ENVIRONMENTAL FATE

6.1 OVERVIEW

Arsenic enters the environment both as the result of natural forces (volcanos and weathering of arsenic-containing rocks) and human activity (metal smelting, glass manufacturing, pesticide production and application, and fossil-fuel burning).

Arsenic in the environment may undergo a complex cycle of chemical interconversions and transfers between media. Atmospheric emissions, which are usually adsorbed to particulate matter, may undergo oxidation before being returned to the surface by wet or dry deposition. Arsenic in water may undergo either reduction or oxidation, depending on pH, the electrochemical oxidation-reduction potential (Eh), and other ions present. Soluble forms of arsenic tend to be quite mobile in water, while less soluble species adsorb to clay or soil particles. Microorganisms in soils, sediments, and water can reduce and methylate arsenic to yield methyl arsines, which volatilize and re-enter the atmosphere. These forms then undergo oxidation to become methyl arsonic acids and ultimately transform back to inorganic arsenic.

6.2 RELEASES TO THE ENVIRONMENT

6.2.1 Anthropogenic

Table 6.1 summarizes releases of arsenic into the environment in 1979 as a result of human activity (EPA 1982b). The total amount of arsenic released was 53,400 Mg, most of which (81%) was deposited on land. The three largest sources of emissions to air and soil are fossil fuel consumption, pesticide use, and copper smelting. These three sources accounted for 35, 26, and 19%, respectively, of total air emissions in 1979, and similar quantities (32, 19, and 19%) of land emissions. The largest sources of arsenic in surface water are urban runoff (37%), pesticide application (25%), and zinc production (20%).

6.2.2 Natural

Table 6.2 summarizes the quantities of arsenic estimated to be released to the environment from natural sources. In the northern hemisphere, the single largest source is volcanic emissions, accounting for 88% of the total releases. Other important natural sources include weathering of arsenic-containing minerals and ores (160 Mg/year), forest fires (110 Mg/year), and the terrestrial biosphere (170 Mg/year).

6.3 ENVIRONMENTAL FATE

6.3.1 Atmosphere

Arsenic released to the atmosphere as a gas vapor or adsorbed to particulate matter may be transported to other media via wet or dry deposition, making the atmosphere an important route of arsenic transfer to other media. Trivalent arsenic may undergo oxidation in the air, and arsenic in the atmosphere is usually a mixture of the trivalent and pentavalent forms (EPA 1984a).

Most arsenic in air is adsorbed to particulate matter, especially small diameter particles (e.g., less than 2 μm in diameter) (Coles et al. 1979, as cited in EPA 1982b). The residence time of particulate-bound arsenic in the air depends on particle size, but a typical value is about 9 days (Walsh et al. 1979, as cited in EPA 1982b). Arsenic may persist longer under conditions of limited atmospheric mixing or low precipitation.

Photolysis is not considered an important fate process for arsenic compounds (Callahan et al. 1979).

6.3.2 Surface Water

Arsenic in surface water can undergo a complex pattern of transformations, including oxidation-reduction reactions, ligand exchange, biotransformation, precipitation, and adsorption (Callahan et al. 1979). This complexity results in extremely mobile behavior in aquatic systems, with much of the arsenic entering rivers and eventually transported to oceans (Callahan et al. 1979). Rate constants for these various reactions are not readily available, but the factors most strongly influencing intramedium fate processes in surface water include Eh, pH, metal sulfide and sulfide ion concentrations, iron concentration, presence of phosphorus minerals, temperature, salinity, and distribution and composition of biota (Callahan et al. 1979).

Sorption onto clays, iron oxides, manganese compounds, and organic material is an important fate of arsenic in surface water (Callahan et al. 1979, EPA 1982b), and sediment serves as a reservoir for much of the arsenic entering surface waters. Sediment-bound arsenic (arsenate/arsenite), which has been methylated by aerobic and anaerobic microorganisms, may be released back to the water column (EPA 1982b).

6.3.3 Groundwater

Soluble forms of arsenic interact with soil and travel with the groundwater mass with which they are associated. Shifts in oxidation state may occur in either direction, depending on the particular physical and chemical characteristics of the soil and groundwater.

Volatilization of methylated forms from groundwater is possible. Nonporous soil and heavy vegetation cover are expected to impede volatilization, and oxidation may transform volatile forms into nonvolatile species or species that will adsorb to clay, organic matter, and iron and aluminum complexes.

6.3.4 Soil

Arsenic occurs in soil predominantly in an insoluble adsorbed form (EPA 1982b). Clay with high anion exchange capacity (e.g., high kaolinite content) is particularly effective at adsorbing arsenate via anion exchange. Complexation and chelation by organic material, iron, or calcium are also important processes fixing arsenic in insoluble form (Cooper et al. 1932, as cited in EPA 1982b).

Red and yellow podzols, latosols, arid and limestone soils, and subsoils high in clay and iron oxides have greater holding capacity for arsenic than other types of soil (Hiltbold et al. 1974, as cited in EPA 1982b). A rise in pH in high iron soil, a drop in pH in lime soil, or a change in redox potential may lead to resolubilization of fixed arsenic.

Leaching of arsenic is usually important only in the top 30 cm of soil (EPA 1982b). Leaching carries arsenic deeper in sandy soils than in clay or loam soils, although EPA (1982b) reports that no leached arsenic could be detected below 90 cm in any of the studies.

While arsenate dominates in aerobic soils, arsenite is the predominant form in slightly reduced soils (e.g., temporarily flooded soil), and arsine, methylated arsenic, and elemental arsenic predominate in very reduced conditions (e.g., swamps and bogs) (EPA 1982b).

6.3.5 Biota

As noted above, arsenic in water and soil may be reduced and methylated by fungi, yeasts, algae, and bacteria, and these forms may volatilize and escape into the air (Wood 1974). The rate of volatilization may vary considerably, depending on soil conditions (oxygenated or anaerobic). The pH value of the soil and microbes present also influence the rate of volatilization. For example, a report by the PAX company (1973) estimated that 50% of an applied dose might volatilize in one year, while Woolson (1976) reported only 1 to 2% volatilization over a period of several months.

Bioconcentration of arsenic occurs in aquatic organisms, primarily in algae and lower invertebrates. Biomagnification in aquatic food chains does not appear to be significant (EPA 1982b, Callahan et al. 1979), although some fish and invertebrates contain high levels of arsenic compounds which are relatively inert toxicologically (EPA 1984a).

Plants may accumulate arsenic via root uptake from soil solution, and certain species may accumulate substantial levels (EPA 1982b). In addition to species differences, the amount of arsenic taken up depends on soil arsenic concentration, soil characteristics, and other factors.

REFERENCE #37

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90



TOXICOLOGICAL PROFILE FOR
SELENIUM

Prepared by:

Clement Associates
under contract No: 205-88-0608

Prepared for:

Agency for Toxic Substances and Disease Registry
U.S. Public Health Service

In collaboration with:

U.S. Environmental Protection Agency

December 1989

5. POTENTIAL FOR HUMAN EXPOSURE

concentrations of 0.10–0.25 mg selenium/L in a settling basin effluent from coal fly ash in North Carolina. Overflow from the ash basin to Belews Lake resulted in surface water selenium concentrations of 0.005–0.020 mg selenium/L in the lake basin. Selenium concentrations of as much as 0.28 mg selenium/L have been reported for raw sewage, 0.045 mg selenium/L for primary effluent, and 0.050 mg selenium/L for secondary effluent (Baird et al. 1972).

5.2.3 Soil

The primary determinant of selenium concentrations in the soil is the selenium content of the parent bedrock materials that releases selenium via weathering processes and leaching (NAS 1976a). Natural weathering processes are thought to release about 100,000–200,000 metric tons of selenium per year (Andren et al. 1975). Atmospheric deposition of selenium also contributes to selenium in the soil. In the past, selenium was used in pesticide products, but because of its stability in soils and subsequent contamination of food crops, its use in pesticide products is restricted. The release of selenium to soil from fly ash settling ponds and hazardous waste sites has not been quantified.

5.3 ENVIRONMENTAL FATE

The behavior of selenium in the environment is influenced to a large degree by its oxidation state and the consequent differences in the behavior of its different chemical compounds (Callahan et al. 1979; NAS 1976a). The oxidation state of selenium in the environment is dependent on ambient conditions, particularly on pH, Eh, and biological activity (Maier et al. 1988).

5.3.1 Transport and Partitioning

The volatile selenium compounds that partition into the atmosphere include the inorganic compounds selenium dioxide and hydrogen selenide and the organic compounds dimethyl selenide and dimethyl diselenide. Hydrogen selenide is highly reactive in air and is rapidly oxidized to elemental selenium and water (NAS 1976a), but the other compounds can persist in air.

Selenium compounds released to the atmosphere can be removed from the atmosphere by dry or wet deposition to soils or to surface water. Selenium concentrations ranging from 0.00004 to 0.0014 mg selenium/L have been detected in rain and snow (Hashimoto and Winchester 1967). Kubota and co-workers (1975) reported selenium concentrations of 0.00002–0.00037 mg selenium/L in rainwater at several locations of the United States and Denmark.

The forms of selenium expected to be found in surface water and the water contained in soils are the salts of selenic and selenious acids. Selenic acid (H_2SeO_4) is a strong acid. The soluble selenate salts of this acid are

5. POTENTIAL FOR HUMAN EXPOSURE

expected to occur in alkaline waters. Sodium selenate is one of the most mobile selenium compounds in the environment owing to its high solubility and inability to sorb onto soil particles (NAS 1976a). Selenious acid (H_2SeO_3) is a weak acid and the diselenite ion predominates in waters between pH 3.5 and 9. Most selenites are less soluble in water than the corresponding selenates (NAS 1980b).

Selenium in the aquatic environment is bioaccumulated by aquatic organisms (Chau and Riley 1965; Ohlendorf et al. 1986a; Rudd and Turner 1983; Saiki and Lowe 1987). Lemly (1985) has reported bioconcentration factors (BCFs) of 150-1,850 and bioaccumulation factors (BAFs) of 1,746-3,975 for selenium in freshwater. In the Kesterson National Wildlife Refuge in the San Joaquin Valley of California, elevated levels of selenium have been measured (dry weight) in algae (average 35 mg selenium/kg), midge larvae (139 mg selenium/kg), dragonfly and damselfly nymphs (average 122 and 175 mg selenium/kg, respectively), and mosquito fish (170 mg selenium/kg; Ohlendorf et al. 1986b). For comparison, the mean concentration of selenium found in fish throughout the United States in the 1976-1977, 1978-1979 and 1980-1981 National Pesticide Monitoring Program (Lowe et al. 1985; May and McKinney 1981; Ohlendorf et al. 1986b) was 0.56, 0.46, and 0.47 mg selenium/kg wet weight, respectively. Similarly, Lemly (1985) found elevated selenium concentrations in aquatic organisms living in a power plant cooling reservoir in North Carolina. The degree of bioaccumulation of selenium exhibited a stable pattern over several years, with selenium concentrations (wet weight) in fishes (6-35 mg selenium/kg) > benthic insects (12-15 mg selenium/kg) > annelids (10-12 mg selenium/kg) > molluscs and crustaceans (5-9 mg selenium/kg) > periphyton (4-6 mg selenium/kg; Ohlendorf et al. 1986a). In fish, selenium was concentrated in visceral tissue (25-35 mg selenium/kg wet weight) more than in skeletal muscle (6-11 mg selenium/kg wet weight). Adams (1976) reported BCFs of 62.1, 14.3, 6.3, 3.2, and 10.5 for selenium in the viscera, gill, head-tail, muscle and whole trout, respectively. The BCFs and BAFs for selenium in visceral tissue (i.e., heart, hepatopancreas, spleen, and gonads) of fish have been estimated to range from 35 to 1,850 and from 1,058 to 3,980, respectively (Lemly 1985, 1982). Lemly (1985) also estimated BAFs for selenium in skeletal muscle of fish to range from 485 to 1,746, depending on the species. Maier et al. (1988) estimated BAFs for selenium by algae to range from 100 to 2,600.

Some evidence indicates that under natural conditions selenium might biomagnify in aquatic organisms (Lemly 1985; Maier et al. 1988; NCDNR 1986; Sandholm et al. 1973). Biomagnification is evidenced by progressively higher concentrations of an element or substance in organisms at successively higher trophic levels. More than fifty percent of the selenium contained in sediments in the ponds and reservoir in the Kesterson National Wildlife Refuge in California may be in organic forms (Maier et al. 1988). This might result from the bioaccumulation of selenate by aquatic plants and subsequent synthesis of organic selenium before the plants die and decay on the bottom.

5. POTENTIAL FOR HUMAN EXPOSURE

In soils, pH and Eh are determining factors in the transport and partitioning of selenium. Elemental selenium is essentially insoluble and may represent a major inert "sink" for selenium introduced into the environment under certain conditions (NAS 1976b). Heavy metal selenides and selenium sulfides, which are also insoluble, predominate in acidic (low pH) soils and soils with high amounts of organic matter. Selenium in this form is immobile and will remain in the soil. The selenides of other metals such as copper and cadmium are of low solubility (NAS 1976b). Sodium and potassium selenites dominate in neutral, well-drained mineral soils, and some soluble metal selenites may be found as well. In alkaline (pH > 7.5), well-oxidized soil environments, selenates are the major selenium species. Due to their high solubility and low tendency to sorb onto soil particles, the selenates are very mobile (Kabatas-Pendias and Pendias 1984) and are readily taken up by biological systems (Klaassen et al. 1986) or leached through the soil. Gerritse et al. (1982) found selenium to be very mobile in sewage sludge leachate. They reported K_d s (distribution coefficient = [concentration of selenium sorbed on soil or rock]/[concentration of selenium in solution]) of 14.9 ml/g for sandy loam and 5.91 ml/g for sludge-treated sandy soils. Selenite forms stable ferric oxide-selenite adsorption complexes in acid or neutral soils (Geering et al. 1968).

In environments favoring the soluble forms of selenium (alkaline and oxidizing conditions), the soluble forms of selenium can be accumulated by plants. Selenium uptake by plants is influenced by many factors including soil type, pH, colloidal content, concentration of organic material, oxidation-reduction potentials in the root-soil environment, and total level of selenium in the soil (Fishbein 1983; Robberecht et al. 1982). Soluble selenates (principally sodium selenate) appear to be responsible for most of the naturally occurring instances of plants accumulating high levels of selenium, although much of the total selenium in soil may be present in other forms (NAS 1976a). The use of lime and plant ash as fertilizers, which would raise the pH of the soil and favor the formation of selenate, has been implicated as a contributing factor in the accumulation of high levels of selenium in crops in certain regions of China (Yang et al. 1988).

5.3.2 Transformation and Degradation

5.3.2.1 Air

Selenium dioxide (SeO_2) released to the air from the combustion of fossil fuels should be largely reduced to elemental selenium by sulfur dioxide formed during the combustion (NAS 1976b). Hydrogen selenide is unstable in air and is oxidized to elemental selenium and water (NAS 1976a). Hazards from hydrogen selenide are expected, therefore, to be confined to occupational settings where the confined gas might build up to hazardous levels despite oxidative losses (NAS 1976a).

REFERENCE #38

NAVAJO SUPERFUND OFFICE
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ABANDONED URANIUM MINE

T. MORRIS JUNE '90

THE MERCK INDEX

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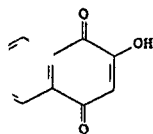
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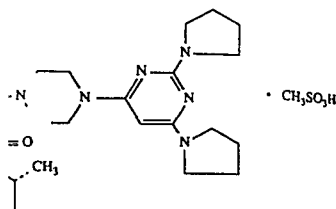
1989

n., *Lythraceae*: Latif, *Indian J. Agr.* 1957, C.A. 55, 14828g (1961). Syn. C m. Soc. 70, 3165 (1948); Jain, Ac Sci. 35A, 233 (1952); Eistert, 1959).



... acid, dec 195-196.
let screen.

... class of nonglucocorticoid, ... which inhibit lipid peroxidation. ... is known as U7406F. ... PCT Int. pat. Appl. 87 01,706 108, 6287u (1987). Inhibition of oxidation in vitro: J. M. Braugher 52, 3438 (1987). Endocrinological Br. ghler et al., *J. Pharmacol. Exp. F. LC determ in plasma: J. W. 'romatog. 424, 293 (1988). In vivo : brain edema: E. D. Hall, M. A. 35 (1988). Effects on experimental D. Hall et al., *J. Neurosurg.* 68, 456 : s al cord ischemia in cats: E. D. of development and potential clin- na and stroke: J. M. McCall et al., 38 417-420 (1987).*



U7406F

... 21-[4-(2,6-di-1-pyrrolidinyl-4-nyl)-16α-methylpregna-1,4,9(11)-thanesulfonate. Monohydrate, mp : 34, 285 nm (ε 52000, 17000).

... izuli; lasurite. Composition: Cl), E. S. Dana, *A System of Mineralogy*, 6th ed., 1901 pp 432-433; C. *Annual of Mineralogy* (John Wiley, 9) 503.

... sh-blue, translucent, cubic or 2. Dec by HCl with pptn of SiO₂

... ornamental furniture, mosaics; in

... bulgaricus factor. Growth ... derived from both animal and ure filtrate of certain microorgan- *Chem.* 177, 933 (1949); Vitucci sh. 34, 409 (1951); Peters et al., *J.* (53). Contains pantetheine q.v. pt. ication to the disulfide, pante- rence of several different forms of disulfide of pantetheine: Rasmus- B. Med. 73, 658 (1950); Brown, 3 (1952). Coenzyme A digested se 2-4 LBF-active compo- *Bacteriol.* 61, 195 (1951). Review:

Snell, Brown, "Pantethine and Related Forms of the Lacto- bacillus Bulgaricus Factor (LBF)" in *Advan. Enzymol.* 14, 49-71 (1953).

5267. Lead. Pb; at. wt 207.2; at. no. 82; valence 2, 4. Four naturally occurring isotopes: 204 (1.40%); 206 (25.2%); 207 (21.7%); 208 (51.7%); artificial, radioactive isotopes: 195-203; 205; 209-214. One of the metals known to the ancient world. Extent of occurrence in earth's crust about 15 g/ton, also expressed as 0.002% (depth of crust: 16 km). Occurs chiefly as sulfide in galena, other minerals include anglesite (PbSO₄), cerussite (PbCO₃), mimetite [PbCl₂·3Pb₃(AsO₄)₂] and pyromorphite [PbCl₂·3Pb₃(PO₄)₂]. Recovery from ore and purification: Heuser, *Metall.* 9, 675 (1955), C.A. 49, 14609 (1955); Ziegfeld, *Eng. Mining J.* 153, 82 (1952), C.A. 46, 2975 (1952). Prep'n of high purity lead: Piontelli, Fagnani, *Chim. Ind. (Milan)* 34, 629 (1952), C.A. 47, 12062 (1953); Giesen, *Technik (Berlin)* 2, 393 (1947), C.A. 42, 852 (1948); Hughes, *J. Electrochem. Soc.* 101, 267 (1954); Baralis, Marone, *Met. Ital.* 59, 494 (1967), C.A. 67, 119613a (1967). Reviews of lead, its alloys and compds: W. Hofmann, *Lead and Lead Alloys, Properties and Technology* (Springer, New York, Eng. Ed., 1970) 551 pp; Abel in *Comprehensive Inorganic Chemistry* vol. 2, J. C. Bailar, Jr. et al., Eds. (Pergamon Press, Oxford, 1973) pp 105-146; H. E. Howe in *Kirk-Othmer Encyclopedia of Chemical Technology* vol. 14 (Wiley-Interscience, New York, 3rd ed., 1981) pp 98-139. Review of carcinogenicity studies of lead and lead compds: *IARC Monographs* 23, 325-415 (1980).

Bluish-white, silvery, gray metal. Highly lustrous when freshly cut, tarnishes upon exposure to air. Very soft and malleable, easily melted, cast, rolled, and extruded. Cubic crystal structure. mp 327.4°; bp 1740°. d₂₀ 11.34; d at mp 10.65; Schneider et al., *Naturwiss.* 41, 326 (1954). Heat of vaporization (1740°) 206 cal/g. Heat capacity (20°): 0.031 cal/g°C. Resistivity (μ-ohm-cm) at 20°: 20.65; at 100°: 27.02; at 320°: 54.76; at 330°: 96.74. Vapor pressure at 1000°: 1.77 mm Hg. E° (aq) Pb/Pb²⁺ +0.126 v. Coefficient of linear expansion (0-100°) 29 × 10⁻⁶, (20-300°) 31.3 × 10⁻⁶, (-183° to +14°) 27 × 10⁻⁶; thermal conductivity varies from 0.083 at 50° to 0.077 at 225°; Franchi, Kingery, *J. Am. Ceram. Soc.* 37, 80 (1954); viscosity of molten lead (327.4°) 3.2 centipoises, (400°) 2.32 cp, (600°) 1.54 cp, (800°) 1.23 cp. Heat capacity and heat of fusion study: Douglas, Dever, *J. Am. Chem. Soc.* 76, 4824 (1954); hardness 1 on Mohs' scale; Brinell hardness (high purity Pb) 4.0; McLellan, *Am. Mineralogist* 30, 635 (1945). Reacts with hot concd nitric acid, with boiling concd hydrochloric or sulfuric acid. Attacked by pure water, weak organic acids in the presence of oxygen. Resistant to tap water, hydrofluoric acid, brine, solvents.

Human Toxicity: Acute: most common in young children with history of pica; anorexia, vomiting, malaise, convulsions due to increased intracranial pressure. May leave permanent brain damage. Blood lead increased above 0.05 mg %. Chronic: children show weight loss, weakness, anemia. Lead poisoning in adults is usually occupational due mainly to inhalation of lead dust or fumes. Wristdrop and colic rarely occur. More often there are vague G.I. and CNS complaints. Pb content of blood > 0.05 mg % and of urine > 0.08 mg per liter support a diagnosis of Pb poisoning. Provocative excretion test using Edathamil may be helpful in confirming excess Pb absorption. Review of toxicity: *Clinical Toxicology of Commercial Products*, R. E. Gosselin et al., Eds. (Williams & Wilkins, Baltimore, 4th ed., 1976) Section III, pp 194-202; *Lead Toxicity*, R. L. Singhal, J. A. Thomas, Eds. (Urban & Schwarzenberg, Baltimore, 1980) 514 pp.

USE: Construction material for tank linings, piping, and other equipment handling corrosive gases and liqs used in the manuf of sulfuric acid, petr refining, halogenation, sulfonation, extraction, condensation; for x-ray and atomic radiation protection; manuf of tetraethyllead, pigments for paints, and other organic and inorganic lead compds; bearing metal and alloys; storage batteries; in ceramics, plastics, and electronic devices; in building construction; in solder and other lead alloys; in the metallurgy of steel and other metals. Review of uses, corrosion metallurgy: Mullarkey, *Ind. Eng. Chem.* 49, 1607 (1957).

5268. Lead Acetate. Neutral lead acetate; normal lead

acetate; sugar of lead; salt of Saturn. C₄H₆O₆Pb; mol wt 325.28. C 14.77%, H 1.86%, Pb 63.70%, O 19.67%. Pb (CH₃COO)₂. Toxicity data: Bradley, Frederick, *Ind. Med.* 10, *Ind. Hyg. Sect.* 2, 15 (1941).

Trihydrate, colorless crystals or white granules or powder; slight acetic odor; slowly effloresces. *Poisonous!* Takes up CO₂ from air and becomes incompletely sol. d 2.55. mp 75° when rapidly heated; at a little above 100° it begins to lose acetic acid; dec completely above 200°. One gram dissolves in 1.6 ml water, 0.5 ml boiling water, 30 ml alcohol; freely sol in glycerol. Aq solns of lead acetate dissolve lead monoxide. pH of 5% aq soln at 25° = 5.5-6.5. *Keep well closed.* *Incompat:* Acids, sol sulfates, citrates, tartrates, chlorides, carbonates, alkalies, tannin, phosphates, resorcinol, salicylic acid, phenol, chloral hydrate, sulfites, vegetable infusions, tinctures. LD₅₀ i.p. in rats: 200 mg/kg (Bradley, Frederick).

Caution: Avoid breathing dust. This substance may reasonably be anticipated to be a carcinogen: *Fourth Annual Report on Carcinogens* (NTP 85-002, 1985) p 121.

USE: Dyeing and printing cottons; weighting silks; manuf lead salts, chrome-yellow; also for various analytical procedures, e.g. detection of sulfide, determination of CrO₃, MoO₃.

THERAP CAT: Astringent.

THERAP CAT (VET): Astringent and sedative (usually in lotions) for bruises and superficial inflammation. Has been used internally in diarrheas.

5269. Lead Antimonate(V). Naples yellow. Approx Pb₃(SbO₄)₂.

Orange-yellow powder. Insol in water, dil acids.

USE: As pigment in oil painting, staining glass, crockery and porcelain.

5270. Lead Arsenate. Approx PbHAsO₄. Occurs in nature as the mineral *schultenite*.

White, heavy powder. *Poisonous!* d 5.79. At about 280° loses H₂O and is converted into pyroarsenate. Insol in water; sol in HNO₃, caustic alkalies. LD₅₀ in rats, rabbits: approx 825, 125 mg/kg orally, Voigt et al., *J. Am. Pharm. Assoc.* 37, 122 (1948).

USE: As constituent of various insecticides for larvae of gypsy moth, boll weevil, etc.

THERAP CAT (VET): Has been used as a teniacide; insecticide.

5271. Lead Arsenite. Approx Pb(AsO₂)₂.

White powder. *Poisonous!* d 5.85. Insol in water; sol in dil HNO₃.

USE: As insecticide like the arsenate.

5272. Lead Azide. N₃Pb; mol wt 291.26. N 28.86%, Pb 71.14%. Pb(N₃)₂. Prep'd from sodium azide and lead nitrate: Schenk in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 763. Most complete description: B. T. Fedoroff et al., *Encyclopedia of Explosives and Related Items* vol. 1 (Picatinny Arsenal, Dover, N.J., 1960) pp A545-A587.

Needles or white powder. Explodes at 350° or on percussion. Heat of formation (25°): +110.5 kcal/mol. Soly in water: 0.023% at 18°; 0.09% at 70°. Freely sol in acetic acid. Insol in NH₄OH.

USE: As primer in explosives. Generally used in the form of dextrinated lead azide.

5273. Lead Borate. Approx Pb(BO₂)₂·H₂O.

White powder. *Poisonous!* Insoluble in water; soluble in dil HNO₃.

USE: Drier for varnishes and paints; with other metals (e.g., Ag) in galvanoplasty for production of conducting coatings on glass, pottery, porcelain, and chinaware.

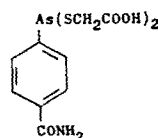
5274. Lead Bromate. BrO₃Pb; mol wt 463.01. Br 34.52%, O 20.73%, Pb 44.75%. Pb(BrO₃)₂.

Monohydrate, colorless crystals. *Poisonous!* d 5.53. Dec at 180°. Slightly sol in cold water, moderately in hot water. *Note:* Pure lead bromate is not dangerous, but when made by pptng lead acetate with an alkali bromate, it may detonate or explode on heating, striking or rubbing because some acetate is occluded.

Consult the cross index before using this section.

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arsino]benzamide; dithioglycolyl *p*-arsenobenzamide; 4-carbamylphenyl bis[carboxymethylthio]arsenite; thioarsenite; thiocarsamide; Caparsolate; Caparside. $C_{11}H_{11}AsNO_5S_2$; mol wt 377.26. C 35.02%, H 3.21%, As 19.86%, N 3.71%, O 21.21%, S 17.00%. Prepd by the condensation of *p*-arsenobenzamide and thioglycolic acid: Gough, King *J. Chem. Soc.* 1930, 669; Maren, *J. Am. Chem. Soc.* 68, 1864 (1946).



White crystalline powder. Sparingly sol in cold water; appreciably sol in water above 90°. Sparingly sol in cold methanol, ethanol; very sol in these solvents when they are warm. Insol in warm isopropyl ether. $pK_a = 4$. The disodium salt is stoichiometrically formed in aq soln at pH 7-8.

Therap Cat (VET): Anthelmintic for heartworm infection in dogs, especially the adult worm.

820. Arsenic. Grey arsenic; metallic arsenic; arsen (German). As; at. wt 74.9216; at. no. 33; valence 3, 5. One natural isotope: 75; artificial, radioactive isotopes: 68-74; 76-81. Arsenic compds were described and used in antiquity, their reduction to the element was known to medieval alchemists, and the first precise directions for the prepn of As are found in Paracelsus' writings (ca. 1520 A.D.). Arsenic occurs probably throughout the universe. Meteorites contain from 0.0005 to 0.1% As. Occurrence in the earth's crust: 0.0005%. Found to a small extent as the element, mostly as an arsenide of true metals. Usually produced as the trioxide when smelting ores for such metals. Reduction with carbon (sugar charcoal) and sublimation in N_2 current yields very pure As: Krepelka, *Coll. Czech. Chem. Commun.* 2, 255 (1930); E. H. Archibald, *The Preparation of Pure Inorganic Substances* (Wiley, New York, 1932) p 269. Other methods: Schenk in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 591-593. Reviews: Gmelin's, *Arsenic* (8th ed.) 17, 475 pp (1952); Smith, "Arsenic, Antimony and Bismuth" in *Comprehensive Inorganic Chemistry* vol. 2, J. C. Bailar, Jr. et al., Eds. (Pergamon Press, Oxford, 1973) pp 547-683. Review of carcinogenicity studies of arsenic and arsenic compds: *IARC Monographs* 23, 39-141 (1980).

Gray, shiny, brittle, metallic-looking rhombohedra. Can be heated to burn in air with bluish flame, giving off an odor of garlic and dense white fumes of As_2O_3 . Loses its luster on exposure to air, forming a black modification + As_2O_3 . Brinell hardness: 147; Mohs' scale: 3.5. $d_4^{25} 5.727$. Sublimes 760° 615° without melting. Vaporization becomes apparent at 100° and is already rapid at 450° . mp 818° at 36 atm. Heat of vaporization 11.2 kcal/g-atom. Heat of sublimation 30.5 kcal/g-atom. Heat of fusion: 22.4 kcal/g-atom: Gmelin's, loc. cit. pp 135-136. Also reported: heat of fusion: 6.620 kcal/g-atom; heat of sublimation 7.63 kcal/g-atom: D. R. Stull, G. C. Sinke, *Thermodynamic Properties of the Elements*, Advances in Chemistry Series 18 (A.C.S., Washington, 1956) pp 11, 44. Specific heat: 0.0822 for 0° to 100° . Dielectric constant = 10.23 at 20° and 60 cycles. Electrical and magnetic properties of crystalline As: Taylor et al., *J. Phys. Chem. Solids* 26, 69 (1965). Insol in water; not attacked by cold H_2SO_4 or HCl; converted by HNO_3 or hot H_2SO_4 into arsenous or arsenic acid.

A yellow modification which has no metallic properties is obtained by sudden cooling of As-vapor. This yellow arsenic is converted back to the gray modification upon very short exposure to ultraviolet light.

Note: In German and other languages Arsenik means arsenic trioxide.

Caution: Most forms of arsenic are toxic. Acute symptoms following ingestion relate to irritation of the G.I. tract: nausea, vomiting, diarrhea which can progress to shock and death. Chronic poisoning can result in exfoliation and pigmentation of skin, herpes, polyneuritis, altered hematopoiesis, degeneration of liver and kidneys: Vallee et al., *Arch.*

Ind. Health 21, 132 (1960); E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd 1969) pp 36-60. This substance and certain arsenic compounds have been listed as known carcinogens: *For Annual Report on Carcinogens* (NTP 85-002, 1985) p 1.

USE: In metallurgy for hardening copper, lead, alloys, the manufacture of certain types of glass. The artificial isotope ^{76}As as radioactive tracer in toxicology.

821. Arsenic Acid. Orthoarsenic acid. AsH_3O_4 ; mol wt 141.93. As 52.78%, H 2.13%, O 45.09%. H_3AsO_4 . Ex only as the hemihydrate. Excessive drying produces As_2O_5 ($5/3H_2O$). Conveniently prepd from As_2O_3 and HNO_3 : mon, Thaler, *Z. Anorg. Allgem. Chem.* 161, 143 (1927); 2 19 (1941).

Hemihydrate, hygroscopic crystals. *Poisonous!* Convert to As_2O_5 by heating above 300° . Freely sol in water, alcohol, glycerol. LD_{50} i.v. in rabbits: 6 mg/kg, Joachimoglu, *J. chem. Z.* 70, 144 (1915).

USE: In the manuf of arsenates.

822. Arsenic Disulfide. *Arsenic sulfide*; red arsenic sulfide; realgar; red orpiment; ruby arsenic; red arsenic gl. C.I. Pigment Yellow 39; C.I. 77085. As_2S_3 ; mol wt 427. As 70.03%, S 29.97%. Prepn: Gmelin's, *Arsenic* (8th 17, pp 417-422 (1952); Schenk in *Handbook of Preparative Inorganic Chemistry* vol 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 603.

Deep red, lustrous monoclinic crystals. mp 320° ; bp $5 d 3.5$. Ignites at high temp. Practically insol in water; sol alkali hydroxides; decomposed by HNO_3 ; very slightly sol hot CS_2 and benzene.

USE: As pigment in painting; in fireworks as blue fire; to give an intense white flame; manuf shot; calico print and dyeing; tanning and depilating hides.

823. Arsenic Hemiselenide. As_2Se ; mol wt 228.78. 65.49%, Se 34.51%. Prepd by melting arsenic and selenium in the correct proportions in a sealed tube filled with nitrogen: Szarvasy, *Ber.* 28, 2654 (1895); 30, 1244 (1897); Gmelin's, *Arsenic* (8th ed.) 17, p 462 (1952).

Black crystals with a metallic luster. Insol in the usual organic and inorganic solvents. Dec in boil. alkali hydroxide solns; slowly decompd by concd hydrochloric and sulfuric acids.

USE: Manuf of glass.

824. Arsenic Pentafluoride. AsF_5 ; mol wt 169.91. 44.09%, F 55.91%. Prepd from As + F_2 : Ruff et al., *Anorg. Allgem. Chem.* 206, 59 (1932); Seel, Detmer, *ibid.* 301, 113 (1959); Kwasnik in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 198. Reviews: Burg in *Fluorine Chemistry* vol. 1, J. Simons, Ed. (Academic Press, New York, 1950) p 102; Kemmitt, Sharp, *Advan. Fluorine Chem.* 4, 208 (1965).

Colorless gas. Forms white clouds in moist air. $d_4^{25} 2$ mp -79.8° . bp -53.2° . Instantly hydrolyzed by water. In alcohol, ether, benzene. Dry AsF_5 does not attack glass, but a minute trace of moisture or HF catalyzes the etch reaction to the point of total destruction.

825. Arsenic Pentaselenide. As_2Se_3 ; mol wt 544.62. 27.51%, Se 72.49%. Prepd by melting the correct proportions of arsenic and selenium in a sealed tube containing nitrogen: Szarvasy, *Ber.* 28, 2654 (1895); 30, 1244 (1897); the action of an arsenic salt on a solution of hydrogen selenide: Moser, Atynsky, *Monatsh.* 45, 235 (1925).

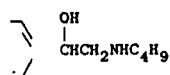
Black, brittle solid with a metallic luster. *Poisonous!* 1 when heated in air. Sol in alkali hydroxides and sulfuric acid; insol in water, dilute acids, concd hydrochloric acid, alcohol, ether, carbon disulfide; dec in nitric acid.

826. Arsenic Pentasulfide. Diarsenic pentasulfide. As_2S_5 ; mol wt 310.12. As 48.31%, S 51.69%. Prepd from H_3AsO_4 and H_2S : Schenk in *Handbook of Preparative Inorganic Chemistry* vol 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 603.

Brownish-yellow, glassy, amorphous, highly refractive mass. Insol in water; sol in alkalis and alkali sulfides. 1 into As_2O_3 , S, and As_2S_3 when boiled with water.

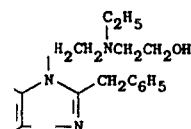
USE: In thin sheets as a light filter; in pigments.

ate: Hajos, Szporny, Arznei-
668).



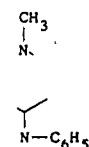
ICl, mp 109-110°.
as lat, Vascutit, Vascunicol, Ro-
Bt tol, Garmian.

[2-[Ethyl(2-hydroxyethyl)amino]-
m-yl-8-(phenylmethyl)-1H-pu-
-ethyl(2-hydroxyethyl)amino]-
zy. -[N-ethyl-N-(β-hydroxyeth-
yl)benzotamophylline; 8102 CB;
); mol wt 385.47. C 62.32%, H
15%. Prepn: Belg. pat. 602,888
5 5981c (1962). Pharmacology:
1 211 (1962). Metabolism:
l-Forsch. 19, 785 (1969). Toxicol-
et al., *ibid.* 18, 460 (1968).



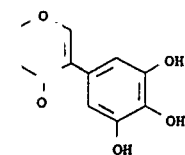
Cl, O₃, AC-3810, BAX 2739Z,
ils np 185-186°. LD₅₀ in mice,
orally; 89, 131 i.p.; 67, 65 i.v.

la
et l-N-phenyl-N-(phenylmethyl)-
n-yl-1-methylpiperidine;
no-1-methylpiperidine; Soventol.
C 81.38%, H 8.63%, N 9.99%.
t. 2,683,714 (1954 to Knoll).
7 icol. Appl. Pharmacol. 3, 393



o nethanol, mp 115°.
l₂Cl₂N₂, Taumidine. Crystals

H, oxy-3-(3,4,5-trihydroxyphen-
yl)-3',4',5'-tetrahydroxyisofla-
286.23. C 62.94%, H 3.52%, O
baptisin. From baptisin by acid
dilatation. From radix Baptisiae:
4 93 (1937). Structure: Böhm,
2 160. Synthesis: Farkas et al.,
also Pseudobaptigenin.



Needles from dil ethanol, mp 284-285°. Begins to sublime
at 240°. Sublimes in oil pump vacuum at 180-200°. uv max
(ethanol): 270.2, 247 nm. Practically insol in water, ammo-
nia water; slightly sol in dil alc, hot glacial acetic acid; sol in
acetone, in NaOH solns.

Tetraacetylaptigenin, C₂₃H₁₈O₁₀, needles from methanol,
mp 214°.

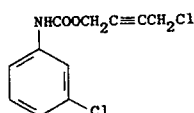
Tetrabenzoylaptigenin, C₄₃H₂₆O₁₀, prisms from metha-
nol, mp 191-192°.

Tetramethylaptigenin, C₁₉H₁₈O₆, crystals from methanol,
mp 144-145°.

968. Baptisia. Wild indigo; indigo weed; false indigo;
yellow indigo. From root of *Baptisia tinctoria* R. Br., *Legu-
minosae*. Habit. North America. Constit. Baptin—a purga-
tive glucoside, baptisin—a bitter glucoside, baptitoxine
(identical with cytosine), an alkaloid.

THERAP CAT: Anti-infective.

969. Barban. (3-Chlorophenyl)carbamic acid 4-chloro-
2-butynyl ester; m-chlorocarbonyl acid 4-chloro-2-butynyl
ester; chloro-2-butynyl m-chlorocarbonyl ester; 4-chloro-2-
butynyl N-(3-chlorophenyl)carbamate; barbamate; barbane;
chlorinat; CS-847; Carbyne. C₁₁H₉Cl₂NO₂; mol wt 258.11.
chlorinat; CS-847; Carbyne. C₁₁H₉Cl₂NO₂; mol wt 258.11.
C 51.19%, H 3.51%, Cl 27.47%, N 5.43%, O 12.40%. Prepn:
Hopkins et al., *J. Org. Chem.* 24, 2040 (1959); U.S. pat.
2,906,614 (1959 to Spencer Chem.); Baskakov et al., *Zh.
Obshch. Khim.* 33, 46 (1963). Activity as an herbicide:
Hoffmann et al., *Weeds* 8, 198 (1960). Metabolism: Gru-
now et al., *Food Cosmet. Toxicol.* 8, 277 (1970). Review:
Abel, *Rep. Progr. Appl. Chem.* 47, 552 (1962).



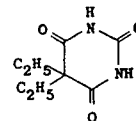
Crystals from n-hexane + benzene, mp 75-76°. Practical-
ly insol in water (soly at 25° = 11 ppm); slightly sol in hex-
ane; readily sol in benzene, ethylene dichloride. Hydrolyzed
by alkali with liberation of the terminal chlorine. Hydrolyzed
under acidic conditions gives 3-chloroacrylic acid. LD₅₀
orally in rats: 600 mg/kg, Bailey, White, *Residue Rev.* 10,
97 (1965).

USE: Selective herbicide for wild oats. Caution: May
cause skin irritation.

970. Barbasco. Name applied in the Spanish-speaking
countries of the New World to many unrelated plants used
to poison or stun fish. In Mexico it usually means roots of
Dioscorea composita Hemsl. or of *Dioscorea tepinapensis*
Uline, *Dioscoreaceae* which yield up to 5% of their dry
weight in diosgenin: *Chem. Week* 79, no. 2, p 20 (July 14,
1956). Isoln procedure: Julian, U.S. pat. 3,019,220 (1962 to
Julian Labs.). Book: D. G. Coursey, *Yams* (Longmans,
London, 1967) 230 pp, an account of the nature, origins,
cultivation and utilization of the useful members of the *Di-
oscoreaceae*. Compare Yam, Mexican.

971. Barberry Bark. Berberis bark; jaundice berry;
woodsour; sowberry; pepperidge bush; sour-spine. Root
bark of *Berberis vulgaris* L., *Berberidaceae*. Habit. Europe
and Western Asia; also U.S. (New England States, Penn-
sylvania and Virginia). Constit. Berberine, berbamine,
oxyacanthine, tannin, wax, fat, resin. Ref: Neugebauer,
Brunner, *Pharm. Zentr.* 80, 113 (1939).

972. Barbital. 5,5-Diethyl-2,4,6-(1H,3H,5H)-pyrimi-
dinetrione; 5,5-diethylbarbituric acid; barbitone; diethylma-
lonylurea; Veronal; Malonal; Veroletten; Sédeval; Dormo-
nal; Hypnogène; Deba; Vespéral; Uronal. C₈H₁₂N₂O₃; mol
wt 184.19. C 52.16%, H 6.57%, N 15.21%, O 26.08%. Prepd
by the condensation of the diethyl ester of diethylmalonic
acid with urea in sodium ethoxide soln: Fischer, Diltthey,
Ann. 335, 334 (1904); Ger. pat. 146,496 (1903), *Frdl.* 7, 651,
Chem. Zentr. 1903, II, 1483; Fischer, v. Mering, *Therapie
der Gegenwart*, March 1903; *Therapeutische Monatsch.* 17, 208
(1903), *Chem. Zentr.* 1903, I, 1155.



Faintly bitter needles (trigonal in the stable phase) from
water, mp 188-192°. Can be sublimed in vacuo. Acid to
litmus. K at 25° = 3.7 × 10⁻³. One gram dissolves in
about 130 ml water, 13 ml boiling water, 14 ml alcohol, 75
ml chloroform, 35 ml ether. Sol in acetone, ethyl acetate,
alkalies, petr ether, acetic acid, amyl alcohol, pyridine, ani-
line, nitrobenzene. LD orally in mice: 600 mg/kg.

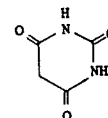
Sodium salt, C₈H₁₁N₂NaO₃, barbitol sodium, sodium 5,5-
diethylbarbiturate, barbitone sodium, soluble barbitol, sodium
diethylmalonylurea, Veronal sodium, Medinal, Embinal.
Bitter crystals or powder. One gram dissolves in 5 ml water,
2.5 ml boiling water, 400 ml alc. Aq soln is alkaline to lit-
mus and phenolphthalein. pH of 0.1 molar aq soln, 9.4.

Caution: May be habit forming. This is a controlled sub-
stance (depressant) listed in the U.S. Code of Federal Regu-
lations, Title 21 Parts 329.1 and 1308.14 (1987).

THERAP CAT: Sedative, hypnotic.

THERAP CAT (VET): Sedative, hypnotic.

973. Barbituric Acid. 2,4,6-(1H,3H,5H)-pyrimidinetri-
one; malonylurea; 2,4,6-trioxohexahydropyrimidine. C₄H₄-
N₂O₃; mol wt 128.09. C 37.50%, H 3.15%, N 21.87%, O
37.47%. Prepn from hydric acid + nitric acid: Baeyer,
Ann. 127, 199 (1863); *ibid.* 130, 129 (1864). Structure:
Mulder, *Ber.* 6, 1233 (1873). Prepd from ethyl malonate and
urea using sodium ethoxide as a condensing agent: Dickey,
Gray, *Org. Syn. coll. vol. II*, 60 (1943). Crystal structure:
Bolton, *Nature* 201, 987 (1964). Unsubstituted barbituric
acid has no hypnotic properties. Review: Carter, *J. Chem.
Ed.* 28, 524 (1951).



Dihydrate, rhombs from water. mp about 248° when
anhydrous, with some decompn. Strong acid. K at 25° =
9.9 × 10⁻³. uv spectrum: Hartley, *J. Chem. Soc.* 87, 1808
(1905). Difficultly sol in cold water; freely sol in hot water,
in dil acids. Forms salts with metals. LD₅₀ orally in male
rats: >5000 mg/kg, E. I. Goldenthal, *Toxicol. Appl. Phar-
macol.* 18, 185 (1971).

USE: Manuf plastics, pharmaceuticals.

* 974. Barium. Ba; at. wt 137.33; at. no. 56; valence 2.
An alkaline earth metal. Abundance in earth's crust 0.05%
by wt. Isotopes: 138 (71.66%); 137 (11.32%); 136 (7.81%);
135 (6.59%); 134 (2.42%); 132 (0.097%); 130 (0.101%).
Occurs in barite and witherite. First prepared as a mercury
amalgam by Davy in 1808. Toxicity studies of barium
compds: Syed, Hosain, *Toxicol. Appl. Pharmacol.* 22, 150
(1972). Reviews: Gmelin's *Handb. Anorg. Chem.*, Barium
(8th ed.) 30, (1960); Goodenough, Stenger, "Magnesium,
Calcium, Strontium, Barium and Radium" in *Comprehensive
Inorganic Chemistry* Vol. 1, J. C. Bailar, Jr. et al., Eds. (Per-
gamon Press, Oxford, 1973) pp 591-664; C. J. Kunesch in
Kirk-Othmer Encyclopedia of Chemical Technology vol. 3
(Wiley-Interscience, New York, 3rd ed., 1978) pp 457-463.

Yellowish-white, slightly lustrous lumps; body-centered
cubic structure; somewhat malleable; very easily oxidizable;
must be kept under petroleum or other oxygen-free liquid to
exclude air. d 3.6. mp approx 710°. bp approx 1600°. E⁰
(aq) Ba²⁺/Ba -2.91 V. Description of reactions which are
characteristic of alkaline earth metals see Calcium. Solns of
sol barium salts give a white ppt with H₂SO₄ or sol sulfates;
they also color nonluminous flame green.

USE: Carrier for radium. The β- and γ-radiation emitted
by ¹⁴⁰Ba + ¹⁴⁰La makes a large contribution to the activity
of the fission products of uranium rods during the first few
weeks after their withdrawal from the reactor. Alloys of Ba
with Al or Mg are used as getters in electronic tubes. The

Consult the cross index before using this section.

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emissions from ^{133}Ba and $^{137\text{m}}\text{Ba}$ are used as standards in γ -spectrometry: Haissinsky, Adloff, *Radiochemical Survey of the Elements* (Elsevier, 1965) pp 12-14. **Caution:** All water or acid soluble barium compounds are *poisonous*!

975. Barium Acetate. $\text{C}_4\text{H}_6\text{BaO}_4$; mol wt 255.45. C 18.81%, H 2.37%, Ba 53.77%, O 25.05%. $\text{Ba}(\text{C}_2\text{H}_3\text{O}_2)_2$. Prepn: *Gmelin's, Barium* (8th ed.) 30, 315 (1932) and supplement, 478 (1960).

Monohydrate. *Poisonous!* d 2.19. Loses its H_2O of hydration at 110° . One gram dissolves in 1.5 ml cold or boiling water, in 700 ml alc. The aq soln is neutral or slightly acid to litmus. LD_{50} in ICR mice: 23.31 mg Ba^{2+} /kg i.v., Syed, Hosain, *Toxicol. Appl. Pharmacol.* 22, 150 (1972).

USE: Mordant for printing fabrics; in lubricating oil and grease; as catalyst for organic reactions.

976. Barium Benzenesulfonate. *Benzenesulfonic acid barium salt.* $\text{C}_{12}\text{H}_{10}\text{BaO}_6\text{S}_2$; mol wt 451.70. C 31.91%, H 2.23%, Ba 30.41%, O 21.25%, S 14.20%. Prepn: Freund, *Ann.* 120, 76 (1861).

Monohydrate, white, nacreous leaflets. *Poisonous!* Freely sol in water; slightly sol in alc.

USE: Lubricating oil additives.

977. Barium Bromate. BaBr_2O_6 ; mol wt 393.19. Ba 34.93%, Br 40.65%, O 24.42%. $\text{Ba}(\text{BrO}_3)_2$. Prepd from potassium bromate and barium chloride: Pearce, Russell, *Inorg. Syn.* 2, 20 (1946).

Monohydrate, monoclinic crystals from hot water. *Poisonous!* May develop slight odor of bromine on long standing. d 3.99. Dec. at 260° . Sol in water (g/100 ml): 0.44 (10°); 0.96 (30°); 5.39 (100°). Sol in acetone. Practically insol in alc, most other organic solvents.

USE: In the prepn of rare earth bromates; as corrosion inhibitor for low-C steel.

978. Barium Bromide. BaBr_2 ; mol wt 297.19. Ba 46.22%, Br 53.78%. Prepn: *Gmelin's, Barium* (8th ed.) 30, 223 (1932) and supplement 380-381 (1960).

Dihydrate, crystals or granules; loses H_2O at 75° and all the H_2O at 120° . *Poisonous!* mp about 850° when anhyd. Very sol in water; sol in methanol; almost insol in ethanol, ethyl acetate, acetone, dioxane.

USE: In the manuf of other bromides; in the prepn of phosphors.

979. Barium Carbonate. CBaO_3 ; mol wt 197.37. C 6.09%, Ba 69.58%, O 24.32%. BaCO_3 . Occurs in nature as the mineral *witherrite*. Prepn: *Gmelin's, Barium* (8th ed) 30, 301-303 (1932) and supplement, 186-188, 461-466 (1960). The barium carbonate of commerce is made by precipitation and is 98-99% pure. Manuf: Faith, Keyes & Clark's *Industrial Chemicals*, F. A. Lowenheim, M. K. Moran, Eds. (Wiley-Interscience, New York, 4th ed., 1975) pp 121-125.

White, heavy powder. *Poisonous!* d (witherrite) 4.2865. At about 1300° dec into BaO and CO_2 . Almost insol in water, 0.024 g in a liter; slightly sol (1:1000) in CO_2 -water; sol in dil HCl, HNO_3 or acetic acid; also sol in soln NH_4Cl or NH_4NO_3 . LD_{50} orally in rats: 800 mg/kg.

Human Toxicity: *Acute:* excessive salivation, vomiting, colic, violent diarrhea, convulsive tremors, increased blood pressure, hemorrhages in G.I. tract and kidneys, muscular paralysis.

USE: Rat poison; in ceramics, paints, enamels, marble substitutes, rubber; manuf of paper, barium salts, electrodes, optical glasses; as an analytical reagent.

980. Barium Chlorate. BaCl_2O_6 ; mol wt 304.27. Ba 45.14%, Cl 23.31%, O 31.55%. $\text{Ba}(\text{ClO}_3)_2$. Prepn: Vanino, *Handb. Präp. Chem. Anorgan. Teil* (2. Aufl., Stuttgart, 1925) p 297; Schmeisser in *Handbook of Preparative Inorganic Chemistry*, Vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 314. Large-scale process: Munroe, *Chem. Met. Eng.* 23, 188 (1920). Also prepd by electrolysis of barium chloride.

Monohydrate, monoclinic prismatic crystals. *Poisonous!* d 3.179. Loses its water of hydration at 120° , begins to give off oxygen at 250° , mp 414° . Freely sol in water; sol in hydrochloric acid; moderately sol in ethylamine; very sparingly sol in alc, somewhat more in acetone. Practically insol in

ethyl acetate, pyridine. Fire hazard when in contact with combustible material.

USE: In pyrotechnics (green fire); manuf of explosives matches; mordant in dyeing.

981. Barium Chloride. BaCl_2 ; mol wt 208.27. 65.95%, Cl 34.05%. Prepn: *Gmelin's, Barium* (8th ed) 171-175 (1932) and supplement, 179-181, 324-325 (1960). Toxicity studies: I. B. Syed, F. Hosain, *Toxicol. Appl. Pharmacol.* 22, 150 (1972). Induction of arrhythmia in animals: F. W. Eichbaum, *Basic Res. Cardiol.* 68, 73 (1973).

Dihydrate, crystals or granules or powder; bitter taste. d 3.86; mp 963. *Poisonous!* Very sol in water; so in methanol. Practically insol in ethanol, acetone, ethyl acetate. LD_{50} in ICR mice (mg Ba^{2+} /kg): 19.2 i.v. (S; Hosain).

USE: Manuf pigments, color lakes, glass, mordant for dyes; weighting and dyeing textile fabrics; in Al refining pesticide; boiler compds for softening water; tanning finishing leather.

THERAP CAT (VET): Formerly used as purgative in hornuminatoric in cattle.

982. Barium Chromate(VI). C.I. 77103; C.I. Pign Yellow 31; Baryta yellow; lemon yellow; permanent yell Steinbühl yellow; ultramarine yellow. BaCrO_4 ; mol 253.37. Ba 54.21%, Cr 20.53%, O 25.26%. Prepn: Be Rieman, *J. Am. Chem. Soc.* 65, 971 (1943); *Colour Index* 4 (3rd ed., 1971) p 4656.

Yellow, heavy, monoclinic, orthorhombic crystals. *Poisonous!* d 4.50. Practically insol in water, dil acetic or chloric acids; dissolved or dec by mineral acids.

USE: As a pigment almost entirely in anticorrosion joining pastes to prevent electro-chemical corrosion at junctions of dissimilar metals; some use in artists' colors and in coloring glass, ceramics, porcelain. Also used in metal prim pyrotechnic compositions.

983. Barium Cyanide. C_2BaN_2 ; mol wt 189.40. 12.68%, Ba 72.52%, N 14.79%. $\text{Ba}(\text{CN})_2$. Prepn: Brit. 602,393 (1948 to I.C.I.); *Gmelin's, Barium* (8th ed.) 30, (1932) and supplement 483 (1960).

Crystals; slowly dec in air. *Very poisonous!* Very so water; sol in alcohol.

USE: In electroplating processes; in metallurgy.

984. Barium Dithionate. Barium "hyposulfate". O_5S_2 ; mol wt 297.48. Ba 46.17%, O 32.27%, S 21.5%. BaS_2O_6 . Prepn: Pfanstiel, *Inorg. Syn.* 2, 170 (1946).

Dihydrate, crystals. *Poisonous!* d 4.54. Loses SO_2 heating above 150° forming BaSO_4 . Sol in 4 parts water more sol in hot water; slightly sol in alcohol.

985. Barium Ferrocyanide. *Barium hexacyanoferrate(II).* $\text{C}_6\text{Ba}_2\text{FeN}_6$; mol wt 486.68. C 14.81%, Ba 56.45%, N 11.48%, Fe 17.27%. $\text{Ba}_2\text{Fe}(\text{CN})_6$. Prepn: Grat-Cabau *Bull. Soc. Chim. France* 1956, 1743.

Hexahydrate, yellowish rectangular monoclinic crystals; loses most of water at 40° becoming colorless. Dec at evolving HCN. Almost insol in water, alcohol.

986. Barium Fluoride. BaF_2 ; mol wt 175.36. 78.33%, F 21.67%. Prepd by dissolving BaCO_3 in ex HF, evaporating to dryness, and heating to red heat: Olbrich, *Thesis* (Technische Hochschule, Breslau, 1929). Kwasnik in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed., (Academic Press, New York, 2nd 1963) p 234.

Transparent cubic crystals (fluorite lattice). *Poisonous* 4.83. mp 1353. bp 2260. Soly in water (g/l): 1.586 (10°); 1.607 (20°); 1.620 (30°). Also sol in hydrochloric, nitrohydrofluoric acids and in aq solns of ammonium chlor May be stored in glass bottles.

USE: As a flux and opacifier in vitreous enamels; in manuf of carbon brushes for D.C. motors and generators heat-treating metals; in embalming; in glass manuf.

987. Barium Formate. $\text{C}_2\text{H}_2\text{BaO}_4$; mol wt 227.40. 10.56%, H 0.89%, Ba 60.40%, O 28.14%. $\text{Ba}(\text{HCO}_2)_2$. Prepn: *Gmelin's, Barium* (8th ed) 30, 311 (1932), and supplement, 477 (1960).

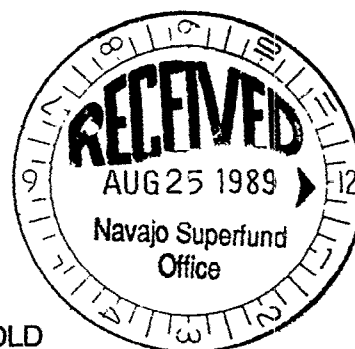
REFERENCE #39


NAVAJO SUPERFUND OFFICE
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INTRODUCTION

Entries in this book include basic chemicals, pesticides, dyes, detergents, lubricants, plastics, drugs, food additives, preservatives, ores, soaps, extracts from plant and animal sources, and industrial intermediates and waste products from production processes. Some of the information refers to materials whose composition is not precisely known. The chemical materials included are assumed to exhibit the reported toxic effect in their pure state unless otherwise noted. However, even in the case of a supposedly "pure" material, there is usually some degree of uncertainty as to its exact composition and the impurities which may be present. This possibility must be considered in attempting to interpret the data presented since the toxic effects observed could in some cases have been caused by a contaminant.

Excluded from our list are tradename products representing compounded or formulated proprietary mixtures available as commercial products. These exclusions are necessary because of difficulties in assessing the contribution of each component of a mixture to that material's total toxicity and because a product's formulation is often changed by varying the components, their concentration, or their purity. Commercial product tradenames as synonyms are included, particularly when they represent a single active chemical entity or a well-defined mixture of relatively constant composition. Radioactive materials are included but the effects reported are the chemically produced effects rather than the radiation effect.

For each material described the following data are provided when available: the material name, Hazard Rating (HR:), CAS number, RTECS number, molecular formula, molecular weight, selected properties including a description of the material (where necessary), synonyms, the U.S. Occupational Safety and Health Administration's (OSHA) air standards, the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values, the German Research Society's (MAK) values, U.S. Department of Transportation (DOT) classifications, and the Toxic and Hazard Review (THR). Each data type is described below.

1. *Name* The name of each material is selected to facilitate recognition of the material. In many cases no single name will be recognized by a majority of readers. Extensive cross-indexing by synonyms is provided to aid in locating an entry.

2. *HR:* is the hazard rating assigned to the material on a scale of 1 to 3 that briefly identifies the level of the toxicity as follows:

The number "3" indicates an LD₅₀ below 400 mg/kg.

The number "2" indicates an LD₅₀ of 400-4,000 mg/kg.

The number "1" indicates an LD₅₀ of 4,000-40,000 mg/kg.

3. *CAS:* is the American Chemical Society's Chemical Abstracts Service Registry Number. It is a numeric designation assigned by the Chemical Abstracts Service and uniquely identifies a

Extracts of species of *Aristolochia* traditionally been used as a bit of a range of therapeutic effects.

The Federal Health Office considers that they have no justifiable use having in view the risks. The regulatory authority relates not only to those containing aristolochic acid but also to other preparations or extracts of plants of the *Aristolochiaceae*. The homeopathic preparations preparation of at least 10^{-11} will remain unchanged. WHO Drug Information Circular (16 October 1981).

HR: 3

Colic infusion

CHABANE * MOUNTAIN TOBACCO

Inhalation and ingestion. A mild irritant and allergen. It can cause gaseous disturbances, and collapse. Contact dermatitis. Combustible and heat or flame. Incompatible with organic materials.

AMINES**HR: 3**

They contain one or more rings of aromatic cyclic HC, such as benzene. A large number of such amines. The primary due to the characteristic odor. The aromatic amines are recognized as toxic to the human bladder, ureter, liver and carcinogenic to the intestine and prostate. See also amines.

SPIRITS OF AMMONIA

A clear liquid, suffocating odor of ammonia. Composition: 10% by weight of NH_3 .

Ammonia. A dangerous fire hazard. High alcohol content. Moderately explosive when heated, emits toxic fumes of ammonia. Incompatible with oxidizing materials.

ACID**HR: 3**

NIOSH: CF 7875000
mw: 217.06

Isolated from aq solns; mp: 232°; bp: 200° @ 15°. Very sol in hot water, insol in ether and benzene.

SYNS: P-AMINO BENZENEARSONIC ACID

* 4-AMINO BENZENEARSONIC ACID * AMINOPHENYLARSINE ACID * P-AMINOPHENYLARSINE ACID * P-AMINOPHENYLARSINIC ACID * P-AMINOPHENYLARSONIC ACID * 4-AMINOPHENYLARSONIC ACID * P-ANILINEARSONIC ACID * ANTOXYLIC ACID * P-ARSANILIC ACID * 4-ARSANILIC ACID * ATOXYLIC ACID

OSHA PEL: TWA 500 ug(As)/m³

THR: Poison by ingestion, intravenous, and intraperitoneal routes. See also arsenic compounds and aniline. A human carcinogen. Flammable, decomposes with heat to yield flammable vapors. When heated to decomposition it or contact with acid or acid fumes emits highly toxic fumes of As and NO_x .

ARSANILIC ACID, MONOSODIUM SALT**HR: 3**

CAS: 127-85-5 NIOSH: CF 9625000
mf: $\text{C}_6\text{H}_7\text{AsNO}_3 \cdot \text{Na}$ mw: 239.05

PROP: Tetra hydrate; white odorless crystalline powder, faint salty taste. Sol in water, somewhat sol in alc.

SYNS: NCI-C61176 * (4-AMINOPHENYL)ARSONIC ACID SODIUM SALT * ANHYDROUS SODIUM ARSANILATE * ARSANILIC ACID SODIUM SALT * ATOXYL * SODIUM AMINARSONATE * SODIUM-P-AMINO BENZENEARSONATE * SODIUM AMINOPHENOL ARSONATE * SODIUM-P-AMINOPHENYLARSONATE * SODIUM-ANILINE ARSONATE * SODIUM ANILARSONATE * SODIUM ARSANILATE * SODIUM-P-ARSANILATE * SODIUM ARSONILATE

OSHA PEL: TWA 500 ug(As)/m³

THR: Poison by subcutaneous route. Can cause blindness. When heated to decomposition it emits very toxic fumes of As and NO_x .

ARSENIC**HR: 3**

CAS: 7440-38-2 NIOSH: CG 0525000
DOT: 1558
mf: As mw: 74.92

PROP: Silvery to black, brittle, crystalline and amorphous metalloid. mp: 814° @ 36 atm, bp: subl @ 612°, d: black crystals 5.724 @ 14°; black amorphous 4.7, vap press: 1 mm @ 372° (sublimes). Insol in water; sol in HNO_3 . See also arsenic vapor.

SYNS: ARSENICALS * ARSENIC-75 * AR-

SENIC BLACK * ARSEN (GERMAN, POLISH)
* COLLOIDAL ARSENIC * GREY ARSENIC
* METALLIC ARSENIC

OSHA PEL: TWA 500 ug/m³

ACGIH TLV: TWA 0.2 mg/m³

TRK: 0.2 mg/m³ calculated as As in that portion of dust that can possibly be inhaled.

DOT Classification: Label: Poison

THR: Poison by subcutaneous, intramuscular, and intraperitoneal routes. Systemic, skin, and gastrointestinal effects. A human carcinogen. An experimental teratogen. Mutagenic data. Flammable in the form of dust when exposed to heat or flame or by chemical reaction with powerful oxidizers such as bromates; chlorates; iodates; peroxides; lithium; NCl_3 ; KNO_3 ; KMnO_4 ; Rb_2C_2 ; AgNO_3 ; NOCl ; IF_5 ; CrO_3 ; ClF_3 ; ClO ; BrF_3 ; BrF_5 ; BrN_3 ; $\text{RbC}\equiv\text{CH}$; $\text{CsC}\equiv\text{CH}$. Slightly explosive in the form of dust when exposed to flame. When heated or on contact with acid or acid fumes, emits highly toxic fumes; can react vigorously on contact with oxidizing materials. Incompatible with bromine azide; dirubidium acetylide; halogens; palladium; zinc; platinum; NCl_3 ; AgNO_3 ; CrO_3 ; Na_2O_2 ; hexafluoro isopropylideneamino lithium. For further information, see Vol. 4, No. 1 of *DPIM Report*.

m-ARSENIC ACID**HR: 3**

CAS: 10102-53-1 NIOSH: CG 0760000
mf: AsHO_3 mw: 123.93

SYN: METAARSENIC ACID

THR: See also arsenic compounds. When heated to decomposition it emits toxic fumes of As.

o-ARSENIC ACID**HR: 3**

CAS: 7778-39-4 NIOSH: CG 7000000
mf: AsH_3O_4 mw: 141.95

SYNS: ACIDE ARSENIQUE LIQUIDE (FRENCH)
* ORTHOARSENIC ACID

OSHA PEL: TWA 500 ug(As)/m³

THR: Poison by ingestion. See also arsenic compounds. When heated to decomposition it emits toxic fumes of As. For further information, see Vol. 2, No. 3 (as Arsenic Acid) in *DPIM Report*.

ARSENIC ACID (SOLUTION)**HR: 3**

CAS: 7778-39-4 NIOSH: CG 0765000

* BIS(2-HYDROXYETHYL)LAURAMIDE * N,N-BIS(2-HYDROXYETHYL)LAURAMIDE * COCONUT OIL AMIDE OF DIETHANOLAMINE * DIETHANOLLAURAMIDE * N,N-DIETHANOLLAURAMIDE * N,N-DIETHANOLLAURIC ACID AMIDE * LAURIC ACID DIETHANOLAMIDE * LAUROYL DIETHANOLAMIDE * LAURYL DIETHANOLAMIDE * NCI-C55323

THR: Suspected experimental carcinogen. Moderately toxic by ingestion. When heated to decomposition, it emits toxic fumes of NO_x .

BIS(HYDROXY METHYL)FURATRIAZINE

HR: 3

CAS: 794-93-4 NIOSH: PC 3200000
mf: $\text{C}_{11}\text{H}_{11}\text{N}_5\text{O}_5$ mw: 293.27

SYNS: 3-BIS(HYDROXYMETHYL)AMINO-6-(5-NITRO-2-FURYLETHENYL)-1,2,4-TRIAZINE * N-(6-(5-NITROFURFURYLIDENEMETHYL)-1,2,4-TRIAZIN-3-YL)IMINODIMETHANOL * ((6-(2-(5-NITRO-2-FURYL)VINYL)-AS-TRIAZIN-3-YL)IMINO)DIMETHANOL * 3-DI(HYDROXYMETHYL)AMINO-6-(5-NITRO-2-FURYLETHENYL)-1,2,4-TRIAZINE

THR: An experimental carcinogen. When heated to decomposition, it emits toxic fumes of NO_x .

BIS(ISSOCTYL OXYCARBONYL METHYL THIO)DIOCTYL STANNANE

HR: 3

CAS: 26401-97-8 NIOSH: WH 6723000
mf: $\text{C}_{36}\text{H}_{72}\text{O}_4\text{S}_2\text{Sn}$ mw: 751.89

SYNS: DISSOCTYL ((DIOCTYLSTANNYLENE)-DITHIO)DIACETATE * DIOCTYL TIN BIS(ISSOCTYL MERCAPTOACETATE) * DIOCTYL TIN-S,S'-BIS(ISSOCTYL MERCAPTOACETATE) * DIOCTYL TIN BIS(ISSOCTYL THIOGLYCOLATE) * DI-N-OCTYL TIN DISSOCTYL THIOGLYCOLATE * DI-N-OCTYL-ZINN-DI-ISSOCTYLTHIOGLYKOLAT (GERMAN)

OSHA PEL: TWA 100 $\mu\text{g}(\text{Sn})/\text{m}^3$ (skin)

THR: Moderately toxic via oral route. See also tin compounds. When heated to decomposition, it emits toxic fumes of SO_x .

1,3-BISMALEIMIDO BENZENE

HR: 3

CAS: 3006-93-7 NIOSH: ON 6125000
mf: $\text{C}_{14}\text{H}_8\text{N}_2\text{O}_4$ mw: 268.24

SYNS: 1,3-DIMALEIMIDOBENZENE * N,N'-(M-PHENYLENE)BISMALEIMIDE * N,N'-(M-PHENYLENE)DIMALAEMIDE

THR: Poison by ingestion and intraperitoneal route. When heated to decomposition, it emits toxic fumes of NO_x .

BIS(METHANE SULFONYL)-D-MANNITOL

HR: 3

CAS: 1187-00-4 NIOSH: OP 2975000
mf: $\text{C}_8\text{H}_{18}\text{O}_{10}\text{S}_2$ mw: 338.38

SYNS: 1,6-BIS-O-METHYLSULFONYL-d-MANNITOL * 1,6-DIMESYL-d-MANNITOL * 1,6-DIMETHANESULFONATE-d-MANNITOL * 1,6-DIMETHANE-SULFONOXY-d-MANNITOL * 1,6-DIMETHANESULPHONOXY-1,6-DIDEOXY-d-MANNITOL * D-MANNITOL BUSULFAN * MANNITOL MYLERAN * NSC-37538

THR: Poison by intravenous route. Moderate intraperitoneal toxicity. Mutagenic data. An experimental neoplastigen. When heated to decomposition, it emits toxic fumes of SO_x .

N,N'-BISMORPHOLINE DISULFIDE

HR: 3

CAS: 103-34-4 NIOSH: QE 3325000
mf: $\text{C}_8\text{H}_{16}\text{N}_2\text{O}_2\text{S}_2$ mw: 236.38

PROP: Tan to gray powder; mp: 122° min; d: 1.36 @ 25°.

SYNS: BISMORPHOLINO DISULFIDE * DIMORPHOLINE DISULFIDE * DIMORPHOLINO DISULFIDE * DITHIOBISMORPHOLINE * 4,4'-DITHIOBIS-(MORPHOLINE) * N,N-DITHIODIMORPHOLINE * 4,4'-DITHIODIMORPHOLINE * 4,4'-DITHIOMORPHOLINE * MORPHOLINODISULFIDE * MORPHOLINE DISULFIDE * USAF B-17 * USAF EK-T-6645

THR: Poison by intraperitoneal and intravenous routes. Moderate oral toxicity. See also morpholine. When heated to decomposition it emits very toxic fumes of NO_x and SO_x .

BISMUTH

HR: 3

CAS: 7440-69-9 NIOSH: EB 2600000
Af: Bi Aw: 208.98

PROP: Hexagonal silver-white or reddish metallic crystals; mp: 271.3°, bp: 1420°-1560°, d: 9.80, vap press: 1 mm @ 1021°.

SYN: BISMUTH-209

THR: Poisonous to man. See also bismuth compounds. Flammable when exposed to flame and by chemical reaction with $[\text{Bi}(\text{OH})_3 + \text{Al}(\text{OH})_3]$; coprecipitated and H_2 reduced yields

injection and intraperitoneal decomposition, it emits SO_x .

SILFONYL)-D-MANNI-

HR: 3

NIOSH: OP 2975000
mw: 338.38

METHYLSULFONYL-d-MANNI-
YL-d-MANNITOL * 1,6-DI-
E-MANNITOL * 1,6-DI-
X-1-MANNITOL * 1,6-
NOXY-1,6-DIDEOXY-d-
MANNITOL BUSULFAN
ER * NSC-37538

intravenous route. Moderate
activity. Mutagenic data. An ex-
citant. When heated to de-
compose it emits very toxic fumes of SO_x .

4-CYCLINE DISUL-

HR: 3

NIOSH: QE 3325000
mw: 236.38

powder; mp: 122° min; d:

OLINO DISULFIDE * DIMOR-
PHOLINO DISULFIDE
NE * 4,4'-DITHIOBIS-
N,N-DITHIODIMORPHOLINE *
HOLINE * 4,4'-DITHIO-
HOLINODISULFIDE
SULFIDE * USAF B-17
5

intraperitoneal and intravenous
toxicity. See also morpho-
decomposition it emits
 SO_x and SO_2 .

HR: 3

NIOSH: EB 2600000

0.98

silvery-white or reddish me-
tallic; mp: 271.3°, bp: 1420°-1560°, d:
1.1 @ 1021°.

0.9

o man. See also bismuth com-
pounds. When exposed to flame and
oxidation with $[\text{Bi}(\text{OH})_3]$ +
oxidized and H_2 reduced yields

a spontaneously flammable product. Moderately
dangerous; can react with acid or acid fumes
to emit toxic fumes. Incompatible with Al ; BrF_3 ;
acids; NOF ; NH_4NO_3 ; HClO_3 ; Cl_2 ; IF_5 ; HNO_3 ;
 HClO_4 . For further information see Vol. 3, No.
5 of *DPIM Report*.

BISMUTH ARSPHENAMINE SULFO- NATE

HR: 3

CAS: 12001-47-7 NIOSH: EB 2625000
mf: $\text{C}_{21}\text{H}_{24}\text{As}_3\text{Bi}_2\text{N}_3\text{O}_{12}\text{S}_3 \cdot 3\text{Na}$ mw:
1318.35

SYNS: BISMARSEN * SULFARSPHENAMINE BIS-
MUTH

THR: A poison via intraperitoneal, intramuscu-
lar routes. See also arsenic compounds and bis-
muth compounds. When heated to decomposi-
tion it emits very toxic fumes of Na_2O , NO_x ,
 SO_x , As and Bi.

BISMUTH COMPOUNDS

HR: 3

THR: Bi and its salts can cause kidney damage,
although the degree of such damage is usually
mild. Large doses can be fatal. Industrially it
is considered one of the less toxic of the heavy
metals, although intoxication has occurred from
its use in medicine. The similarity between the
pharmacologic and toxic behaviors of lead and
Bi has been pointed out in the literature. Like
lead, Bi may be liberated from tissue deposits
during periods of acidosis. Serious and some-
times fatal poisoning may occur from the injec-
tion of large doses into closed cavities and from
extensive application to burns. Death of animals
from Bi nephritis following injections of soluble
salts occurs within several hours to 24 days,
the time being generally inversely proportional
to the dose, and it appears to be in the order
of 5-10 times higher than the dose by slow
intravenous injection for rabbits. It is stated that
the administration of Bi should be stopped when
gingivitis appears, for otherwise serious ulcer-
ative stomatitis is likely to result. Other toxic
results may develop, such as malaise, albumin-
uria, diarrhea, skin reactions and sometimes seri-
ous exodermitis. Industrial Bi poisoning has
not been reported, although Bi absorbed in in-
dustrial cases may complicate a diagnosis of
plumbism, since the dark line in the gums, which
is often present in lead poisoning, is also pro-
duced by bismuth. All Bi compounds do not
have equal toxicity. See also individual entries.

Treatment and Antidotes: Personnel show-
ing some of the symptoms noted above which

might indicate that they were absorbing too
much Bi into the body should be removed from
exposure as soon as possible. Get medical ad-
vice. Personnel should be cautioned against
careless handling of these materials.

BISMUTH DIMETHYL DITHIOCARBA- MATE

HR: 3

CAS: 21260-46-8 NIOSH: EB 3400000
mf: $\text{C}_9\text{H}_{18}\text{N}_3\text{S}_6 \cdot \text{Bi}$ mw: 569.64

SYNS: BISMATE * TRIS(DIMETHYLDITHIO-
CARBAMATO)BISMUTH

THR: An experimental tumorigen. See also bis-
muth compounds and thiocarbamic acid. When
heated to decomposition, it emits very toxic
fumes of SO_x and NO_x .

BISMUTH NITRATE

HR: 3

CAS: 10361-44-1 NIOSH: EB 2984400
mf: BiN_3O_9 mw: 395.01

PROP: Triclinic, colorless, slightly hygroscopic
crystals. bp: $-\text{H}_2\text{O}$ @ 80°, d: 2.83, mp: 30°
(decomp).

SYN: NITRIC ACID, BISMUTH(3+) SALT

THR: An intravenous poison. Moderate intra-
peritoneal toxicity. See also Bi compounds and
nitrates.

BISMUTH PENTAFLUORIDE

HR: 3

mf: BiF_5 mw: 303.98

PROP: Crystals. Sublimes @ 550°.

THR: An irritant poison via oral and inhalation
routes. Decomposes readily on contact with
moisture to yield O_3 and bismuth trifluoride.
See fluorides and ozone. Very dangerous. When
heated to decomposition it emits highly toxic
fumes of F^- . Incompatible with water and petro-
latum @ $> 50^\circ$; moisture; acids. Reacts vio-
lently liberating much heat and ozone.

BISMUTH SODIUM THIOGLYCOL- LATE

HR: 3

CAS: 150-49-2 NIOSH: EB 2984000
mf: $\text{C}_6\text{H}_6\text{BiNa}_3\text{O}_6\text{S}_3$ mw: 548.25

SYNS: SODIUM BISMUTH THIOGLYCOLATE
* SODIUM BISMUTH THIOGLYCOLLATE
* THIOBISMOL

THR: A poison via intraperitoneal, intravenous,
and intramuscular routes. A systemic toxicant
in children. See also Bi compounds. When

MOCA**HR: 3**

CAS: 101-14-4

NIOSH: CY 1050000

mf: $C_{13}H_{12}Cl_2N_2$

mw: 267.17

SYNS: DI-(4-AMINO-3-CHLOROPHENYL)METHANE

* DI-(4-AMINO-3-CHLOROPHENYL)METANO (ITALIAN) * 4,4'-DIAMINO-3,3'-DICHLORODIPHENYLMETHANE * 3,3'-DICHLOR-4,4'-DIAMINODIPHENYLMETHAN (GERMAN) * 3,3'-DICHLORO-4,4'-DIAMINODIPHENYLMETHANE * 3,3'-DICLORO-4,4'-DIAMINODIFENILMETANO(ITALIAN) * 4,4'-METHYLENE(BIS)-CHLOROANILINE * METHYLENE 4,4'-BIS (O-CHLOROANILINE) * P,P'-METHYLENEBIS(ALPHA-CHLOROANILINE) * 4,4'-METHYLENEBIS(O-CHLOROANILINE) * P,P'-METHYLENEBIS(O-CHLOROANILINE) * 4,4'-METHYLENEBIS(2-CHLOROANILINE) * 4,4'-METHYLENEBIS-2-CHLOROBENZENAMINE * 4,4-METILENE-BIS-O-CLOROANILINA (ITALIAN)

THR: An experimental carcinogen. Mutagenic data. When heated to decomposition it emits very toxic fumes of Cl^- and NO_x . For further information see Vol. 5, No. 2 of *DPIM Report*.

MOLYBDENUM**HR: 3**

CAS: 7439-98-7

NIOSH: QA 4680000

af: Mo

aw: 95.94

PROP: Cubic, silver-white metallic crystals or gray-black powder; mp: 2622°; bp: approx 4825°; d: 10.2; vap press: 1 mm @ 3102°.

ACGIH TLV: TWA (soluble compounds) 5 mg/m³; (insoluble compounds) 10 mg/m³

DFG MAK: (insoluble compounds) 15 mg/m³; (soluble compounds) 5 mg/m³

THR: Poison by intraperitoneal and intratracheal routes. See also molybdenum compounds. Flammable in the form of dust; when exposed to heat or flame, violent reaction with BrF_3 ; ClF_3 ; F_2 ; PbO_2 . See also iron dust. A mild explosive in the form of dust, when exposed to flame. See also powdered metals. Incompatible with oxidants.

MOLYBDENUM COMPOUNDS**HR: 3**

THR: Poison by subcutaneous and intraperitoneal routes. Molybdenum and its compounds are highly toxic based upon animal experiments. But in spite of their considerable use in industry, human industrial poisoning by molybdenum inhalation has yet to be reported. It is suggested that suitable precautions should be taken against human inhalation of significant amounts of the

more soluble molybdenum compounds. Molybdenum is rapidly excreted by the body. Recent studies have shown that molybdenum has importance as a trace element in the normal growth and development of certain forms of plant life. It is found also in animal tissue, although its precise function is unknown. It is a common air contaminant.

MOLYBDENUM PENTA-CHLORIDE**HR: 3**

CAS: 10241-05-1

NIOSH: QA 4690000

mf: Cl_5Mo

mw: 273.19

PROP: Green-black solid, dark-red as liquid or vapor; hygroscopic, reacting with water and air, sol in dry ether, dry alc and other anhydrous organic solvents; mp: 194°; bp: 268°; d: 2.9. DOT Classification: ORM-B, Label: None

THR: Poison. See also HCl and molybdenum compounds. Dangerous. See also chloride.

MOLYBDENUM TRIOXIDE**HR: 3**

CAS: 1313-27-5

NIOSH: QA 4725000

mf: MoO_3

mw: 143.94

PROP: White or yellow to sltly bluish powder or granules; sol in 1000 parts water (low solubility in H_2O), in conc mineral acids and solutions of alkali hydroxides, ammonia or potassium bitartrate which solidifies to a yellowish-white mass and sublimates at higher temp; mp: 795°; bp: 1155°; d: 4.696 @ 26°/4°

SYNS: MOLYBDIC ANHYDRIDE * MOLYBDIC TRIOXIDE

OSHA PEL: TWA 5 mg(Mo)/m³

THR: Poison by ingestion, inhalation, subcutaneous, and intraperitoneal routes. An experimental neoplastigen. Human pulmonary effects. A powerful irritant. See also molybdenum. Violent reaction with ClF_3 ; Li; Mg; K; Na. Incompatible with interhalogens; metals.

MONOCHLORODIFLUOROMETHANE**HR: 3**

CAS: 75-45-6

NIOSH: PA 639000

mf: $CHClF_2$

mw: 86.47

PROP: Gas; d: 3.87 air @ 0°; mp: -146°; bp: -40.8°; autoign temp: 1170°F.

SYNS: CHLORODIFLUOROMETHANE * DIFLUOROCHLOROMETHANE * DIFLUOROMONOCHLOROMETHANE * FLUOROCARBON-22 * FREON

POTASSIUM

5-99-7 NIOSH: TP 1850000 **HR: 3**
 K_2 mw: 415.09

sol. in water, mp: decomp
 3.499 @ 24°.

AS: JM CHLOROPLATINITE * PO-
 AT: DCHLORIDE * POTASSIUM
 OPLATINATE (II)

humans by ingestion. Poison
 al route. Mutagenic data. Severe
 irritant by intraduodenal route. See
 compounds. When heated to de-
 emits toxic fumes of Cl^- .

06-4 NIOSH: TP 2160000 **HR: 3**
 n: 95.09

er, white, malleable, ductile metal.
 r; mp: 1772°; bp: 3827°; d: 21.45

TM: M BLACK * PLATINUM SPONGE
 5 * LIQUID BRIGHT PLATINUM
 (EPA) (AN)
 /: WA (metal) 1 mg/m³; (soluble)
 0.002 mg/m³
 0.002 mg/m³

mental tumorigen. See also plat-
 u. ls. Incompatible with acetone,
 ride; arsenic; dioxxygen difluoride;
 ra- ne; hydrogen; air; hydrogen per-
 m onoxides; peroxy monosulphuric
 ious; selenium, tellurium. For fur-
 tion see Vol. 1, No. 3 of *DPIM*

CHLORIDE **HR: 3**
 -65-7 NIOSH: TP 2275000
 mw: 265.99

green powder. D: 5.87. Insol
 ether, benzene, chloroform.

OF PLATINUM * PLATINOUS

by ingestion and other routes. A
 tagenic data. See also platinum
 en heated to decomposition it
 fumes of Cl^- .

() CHLORIDE **HR: 3**
 -1 NIOSH: TP 2275500
 mw: 336.89

SYN: PLATINUM TETRACHLORIDE

THR: Poison by ingestion, intravenous, and in-
 traperitoneal routes. Mutagenic data. A severe
 skin irritant. See also platinum compounds.
 When heated to decomposition it emits toxic
 fumes of Cl^- .

PLATINUM COMPOUNDS

THR: Exposure to complex platinum salts has
 been shown to cause symptoms of intoxication
 such as wheezing, coughing, running of the
 nose, tightness of the chest, shortness of breath
 and cyanosis; exposure to dust of pure metallic
 platinum causes no intoxication. Furthermore,
 many people working with platinum salts are
 troubled with dermatitis. This seems only to
 be true of complex platinum salts. It does not
 include the complex salts of the other precious
 metals. Platinum amine nitrates and perchlorates
 either detonate when heated or are impact-sensi-
 tive.

PLIOFILM

CAS: 9006-00-2 **HR: 3**
 NIOSH: TP 3710000
 mf: $(\text{C}_3\text{H}_5\text{Cl})_n$

SYNS: PERMASEAL * RUBBER HYDROCHLO-
 RIDE * RUBBER HYDROCHLORIDE POLYMER

THR: An experimental carcinogen. When
 heated to decomposition it emits toxic fumes
 of Cl^- .

PLUTONIUM

af: Pu aw: 242

PROP: A silvery radioactive metal, chemically
 reactive; mp: 641°; bp: 3232°; d: 19.816 @
 20°/4°.

THR: The permissible levels for plutonium for
 health reasons are the lowest for any of the
 radioactive elements. This is occasioned by the
 concentration of plutonium directly on bone sur-
 faces, rather than the more uniform bone distri-
 bution shown by other heavy elements. This
 increases the possibility of damage from equiva-
 lent activities of plutonium and has led to the
 adoption of the extremely low permissible levels
 given. Radiation Hazard: Artificial isotope
 ^{238}Pu , $T_{1/2} = 86$ Y, decays to radioactive ^{234}U
 via alphas of 5.5 MeV. Artificial isotope ^{239}Pu ,
 $T_{1/2} = 24,000$ Y decays to radioactive ^{235}U via
 alphas of 5.1 MeV. Artificial isotope ^{240}Pu ,
 $T_{1/2} = 6600$ Y decays to radioactive ^{236}Pu (Neptu-

nium Series), $T_{1/2} = 13$ Y decays to radioactive
 ^{241}Am via betas of 0.02 MeV. Artificial isotope
 ^{242}Pu , $T_{1/2} = 3.8 \times 10^5$ Y decays to radioactive
 ^{238}U via alphas of 4.9 MeV. Incompatible with
 carbon tetrachloride; water; air.

PLUTONIUM COMPOUNDS

THR: The toxicity of plutonium compounds is
 based first upon the very high radiotoxicity of
 the plutonium atom and secondly upon whatever
 atoms or combinations of atoms they might con-
 tain. See also plutonium. Very dangerous! Any
 disaster which could cause quantities of pluto-
 nium or plutonium compounds to be scattered
 about the environment can cause great ecologi-
 cal stress and render areas of the land unfit
 for public occupancy.

PLUTONIUM NITRATE (SOLUTION)

CAS: 14913-29-2 NIOSH: TP 6670000

SYN: PLUTONIUM NITRATE SOLUTION (DOT)

DOT Classification: Label: Radioactive

THR: See plutonium. When heated to decompo-
 sition it emits toxic fumes of NO_x .

PODOPHYLLIN

CAS: 9000-55-9 **HR: 3**
 NIOSH: TP 8925000

PROP: Light yellow powder or small yellow
 fragile lumps. Bitter, acrid taste.

SYNS: PODOPHYLLUM * PODOPHYLLUM RESIN

THR: Poison by ingestion, subcutaneous, intra-
 peritoneal, and other unspecified routes. An ex-
 perimental neoplastigen. Combustible. An irri-
 tant to skin, eyes, and mucous membranes.
 When heated to decomposition it emits acrid
 smoke and fumes. For further information see
 Vol. 1, No. 3 of *DPIM Report*.

POLONIUM

af: Po am: 210

PROP: A low melting, radioactive, volatile,
 naturally occurring metallic element; mp: 254°;
 bp: 962°; d: 9.4.

SYN: RADIUM F

THR: Severe radiotoxicity. Very dangerous to
 handle. An experimental carcinogen. See also
 plutonium. Radiation Hazard: Natural isotope
 ^{210}Po (radium-F, Uranium Series), $T_{1/2} = 138$
 D. Decays to stable ^{206}Pb via alphas of 5.3
 MeV.

by radioactive elements and radioisotopes (decay of atomic nucleus); (b) x-rays, generated by sudden stoppage of fast-moving electrons; (c) subatomic charged particles (electrons, protons, deuterons) when accelerated in a cyclotron or betatron. The term is restricted to electromagnetic radiation at least as energetic as x-rays, and to charged particles of similar energies. Neutrons also may induce ionization. Such radiation is strong enough to remove electrons from any atoms in its path, leading to the formation of free radicals. These short-lived but highly reactive particles initiate decomposition of many organic compounds. Thus ionizing radiation can cause mutations in DNA and in cell nuclei; adversely affect protein and amino acid mechanisms; impair or destroy body tissue; and attack bone marrow, the source of red blood cells. Exposure to ionizing radiation for even a short period is highly dangerous, and for an extended period may be lethal. The study of the chemical effects of such radiation is called radiation chemistry or (in the case of body reactions) radiation biochemistry.

RADIUM

af: Ra aw: 226

HR: 3

PROP: A radioactive earth metal. Brilliant white, tarnishes in air. Decomp in water; mp: 700°; bp: 1737°; d: 5.5.

THR: A highly radiotoxic element. 1 g emits 3.7×10^{10} dps. Inhalation, ingestion, or bodily exposure can lead to lung cancer, bone cancer, osteitis, skin damage, and blood dyscrasias. A common air contaminant. Ra replaces calcium in the bone structure and is a source of irradiation to the blood forming organs. The ingestion of luminous dial paint prepared from radium was the cause of death of many of the early dial painters before the hazard was fully understood. The data on these workers has been the source of many of the radiation precautions and the maximum permissible levels for internal emitters which are now accepted. ^{226}Ra is the parent of radon and the precautions described under ^{222}Rn should be followed. ^{228}Ra is a member of the thorium series. It was a common constituent of luminous paints, and while its low beta energy was not a hazard, its daughters in the series may have been a causative agent in the deaths of the radium dial painters following World War I. Its metabolism is the same as any other radium isotope and it is a source of

thoron. The precautions recommended under ^{220}Rn should be followed. Highly dangerous, must be kept heavily shielded and stored away from possible dissemination by explosion, flood, etc. Radiation Hazard: Natural isotope ^{223}Ra (Actinium-X, Actinium Series), $T_{1/2} = 11.4$ D, decays to radioactive ^{219}Rn by alphas of 5.5-5.7 MeV. Natural isotope ^{224}Ra (Thorium-X, Thorium Series), $T_{1/2} = 3.6$ D, decays to radioactive ^{220}Rn by alphas of 5.7 MeV. Natural isotope ^{226}Ra (Uranium Series), $T_{1/2} = 1600$ Y, decays to radioactive ^{222}Rn by alphas of 4.8 MeV. Natural isotope ^{228}Ra (Mesothorium = 1, Thorium Series), $T_{1/2} = 6.7$ Y, decays to radioactive ^{228}Ac by betas of 0.05 MeV.

RADON

mf: Rn mw: 86

HR: 3

PROP: Colorless, odorless, inert gas, very dense. Bp: -62°; d (gas @ 1 atm and 0°): 9.73 g/L, (liq @ bp): 4.4.

THR: A common air contaminant. Radiation Hazard: Natural isotope ^{220}Rn (Thoron, Thorium Series), $T_{1/2} = 55$ s, decays to radioactive ^{216}Po by alphas of 6.3 MeV. Natural isotope ^{222}Rn (Uranium Series), $T_{1/2} = 3.8$ D, decays to radioactive ^{218}Po by alphas of 5.5 MeV. The permissible levels are given for ^{222}Rn in equilibrium with its daughters. The chief hazard from this isotope is inhalation of the gaseous element and its solid daughters, which are collected on the normal dust of the air. This material is deposited in the lungs and has been considered to be a major causative agent in the high incidence of lung cancer found in uranium miners. Radon and its daughters build up to an equilibrium value in about a month from radium compounds, while the build-up from uranium compounds is negligible. Good ventilation of areas where radium is handled or stored is recommended to prevent accumulation of hazardous concentrations of Rn and its daughters.

RED SQUILL**HR: 3**
NIOSH: VF 3750000

PROP: Sea onion bulbs contain a potent concentration of Scilliroside, a glycoside bearing a close chemical resemblance to the Scillarens

SYNS: BONIDE TOPZOL RAT BAITS AND KILLING SYRUP * SCILLIROSIDE GLYCOSIDE * SQUILL

THR: Poison by ingestion. Human gastrointesti-

7-2 NIOSH: VQ 2000000
 HR: 3
 mental carcinogen. See also
 heated to decomposition it
 fumes of Cl^- .

Cl₂ NIOSH: VQ 4200000
 HR: 3
 mw: 140.15

Liquid. Sol in water, methanol,
 anol, ethyl acetate; slightly sol in
 from *Streptomyces sp.*

M⁺ IN

perimental teratogen and carcino-
 te toxic by intravenous, subcuta-
 ir aperitoneal routes. Mutagenic
 heated to decomposition it emits
 and fumes.

AS NIOSH: VQ 5946000
 HR: 3

el wish, reddish volatile oil, pun-
 tic odor and taste. Sol alc, ether,
 glacial acetic acid, CS_2 ; d: 1.065-
 5°, 5°. Saffrole-Free ethanol extract
 a idum root bark.

FRAS ALBIDUM

erimental neoplastigen. When
 ec nposition it emits acrid smoke

M

mw: 44.9559

ia ally occurring element.

Earth. Should be handled care-
 imable in the form of dust, when
 ne or flame or by chemical reaction
 ei See also powdered metals, and
 . Can react violently with halogens;

M (3⁺) CHLORIDE NIOSH: VQ 8925000
 HR: 3
 mw: 151.31

ite deliquescent solid. Mp: 960°. sol
 in alc.

SYN: SC G3

THR: Poison by intraperitoneal route. Moder-
 ately toxic by ingestion. See also scandium.
 When heated to decomposition it emits toxic
 fumes of Cl^- .

SCARLET RED NIOSH: QL 5775000
 HR: 3
 CAS: 85-83-6
 mf: $\text{C}_{24}\text{H}_{20}\text{N}_4\text{O}$ mw: 380.48

SYNS: BRASILAZINA OIL RED B * CALCO OIL
 RED D * C.I. 258 * C.I. SOLVENT RED 24
 * 2',3-DIMETHYL-4-(2-HYDROXYNAPHTHY-
 LAZO)AZOBENZENE * FAST OIL RED B
 * FAT RED B * 1-((2-METHYL-4-((2-METH-
 YLPHENYL)AZO)PHENYL)AZO)-2-NAPHTHALENOL
 * PHENOPLASTE ORGANOL RED B
 * RUBRUM SCARLATINUM * 1-((4-(O-TOLYL-
 AZO)-O-TOLYL)AZO)-2-NAPHTHOL * O-TOL-
 UENEAZO-O-TOLUENEAZO-BETA-NAPHTHOL
 * O-TOLUENEAZO-O-TOLUENE-BETA-NAPHTHOL
 * O-TOLYLAZO-O-TOLYLAZO-BETA-NAPHTHOL
 * O-TOLYLAZO-O-TOLYLAZO-2-NAPHTHOL

THR: An experimental carcinogen. Mutagenic
 data. When heated to decomposition it emits
 toxic fumes of NO_x .

SCOPOLAMINE NIOSH: VR 3675000
 HR: 3
 CAS: 51-34-3
 mf: $\text{C}_{17}\text{H}_{21}\text{NO}_4$ mw: 303.39

PROP: Thick, colorless, syrupy liquid alkaloid.
 Mp: 55°. Very sol in hot water, alc, ether, chlo-
 roform, acetone; slightly sol in benzene, petro-
 leum ether. Decomp on standing.

SYNS: 6-BETA,7-BETA-EPOXY-3-ALPHA-TROPA-
 NYL S-(-)-TROPATE * EPOXYTROPINE TROPATE
 * HYOSCINE * (-)-HYOSCINE * SCOPINE
 TROPATE * (-)-SCOPOLAMINE * TROPIC
 ACID, ESTER WITH SCOPINE * TROPIC ACID, 9-
 METHYL-3-OXA-9-AZATRICYCLO(3.3.1.0(SUP 2,
 4))NON-7-YL ESTER

THR: Poisonous alkaloid by intravenous and
 subcutaneous routes. Human central nervous
 system effects. See also esters. It can produce
 profound depression of the central nervous sys-
 tem and occasionally it causes excitement. It
 can cause hallucinations and the individual af-
 fected loses a certain amount of his normal inhi-
 bitory control. It is for that reason that it has
 been called "truth serum." In many cases of

poisoning from this material, and even to a cer-
 tain extent following its medical application,
 there is retention of the urine caused by paralysis
 of the bladder, and catheterization is necessary.
 The fatal dose is variable. Death has occurred
 from as little as 0.6 mg, while recovery has
 occurred from doses of 7-15 mg. Dangerous;
 when heated to decomposition it emits highly
 toxic fumes of NO_x .

SECONAL NIOSH: CP 9450000
 HR: 3
 CAS: 76-73-3
 mf: $\text{C}_{12}\text{H}_{18}\text{N}_2\text{O}_3$ mw: 238.32

SYNS: 5-ALLYL-5-(1-METHYLBUTYL)BARBITU-
 RIC ACID * 5-ALLYL-5-(1-METHYLBUTYL)-
 MALONYLUREA * QUINALBARBITAL
 * QUINALBARBITONE * SECOPARBITAL
 * SECOPARBITONE

THR: Poison by ingestion, intraperitoneal, sub-
 cutaneous, and intravenous routes. Human cen-
 tral nervous system effects. See also barbitu-
 rates. When heated to decomposition it emits
 toxic fumes of NO_x .

SELENIUM NIOSH: VS 7700000
 HR: 3
 CAS: 7782-49-2
 DOT: 2658
 af: Se aw: 78.96

PROP: Steel gray, non-metallic element; mp:
 170°-217°; bp: 690°; d: 4.81-4.26; vap press:
 1 mm @ 356°.

SYNS: SELENIUM ALLOY * SELENIUM BASE
 * SELENIUM HOMOPOLYMER * C.I. 77805
 * ELEMENTAL SELENIUM * SELEN (POLISH)
 * SELENIUM DUST

OSHA PEL: TWA 200 $\mu\text{g}(\text{Se})/\text{m}^3$
 ACGIH TLV: TWA 0.2 mg/m^3
 DFG MAK: 0.1 mg/m^3
 DOT Classification: Poison B, Label: Poison

THR: Poison by inhalation, intravenous, and
 other unknown routes. An experimental carcino-
 gen. See also selenium compounds. When
 heated to decomposition it emits toxic fumes
 of Se. Can react violently with barium carbide;
 bromine pentafluoride; calcium carbide; chlo-
 rates; chlorine trifluoride; chromic oxide (CrO_3);
 fluorine; lithium carbide; lithium silicon (Li_2Si_2);
 nickel; nitric acid; sodium; nitrogen trichlo-
 ride; oxygen; potassium; potassium bromate; ru-
 bidium carbide; zinc; silver bromate; strontium

carbide; thorium carbide; uranium. For further information see Vol. 1, No. 3 of *DPIM Report*.

SELENIUM COMPOUNDS**HR: 3**

THR: Poison by inhalation and intravenous routes. An experimental carcinogen. Selenium in small amounts is essential for normal growth of some animals. Deficiency or excess is associated with serious disease in livestock. Long-term exposure may be a cause of amyotrophic lateral sclerosis in humans, just as it may cause "blind staggers" in cattle. Elemental selenium has low acute systemic toxicity, but dust or fumes can cause serious irritation of the respiratory tract. Hydrogen selenide resembles other hydrides in being highly toxic, and selenium oxychloride is a vesicant. Some organoselenium compounds have the high toxicity of other organometals. Inorganic selenium compounds can cause dermatitis. Garlic odor of breath is a common symptom. Pallor, nervousness, depression and digestive disturbances have been reported in cases of chronic exposure. Selenium compounds are common air contaminants.

SELENIUM DIMETHYLDITHIO-CARBAMATE**HR: 3**

CAS: 144-34-3 NIOSH: VT 0780000
mf: $C_{12}H_{24}N_4S_8 \cdot Se$ mw: 559.84

PROP: Yellow powder, cryst; d: 1.58; M range: 140°-172°.

SYNS: METHYL SELENAC * TETRAKIS-(DIMETHYLCARBAMODITHIOATO-S,S')SELENIUM

THR: An experimental carcinogen. See also selenium compounds and carbamates. When heated to decomposition it emits very toxic fumes of Se, SO_x , and NO_x .

SELENIUM DISULFIDE (2.5%) SHAM-POO**HR: 2**

NIOSH: VS 9285000

SYN: SELENIUM(IV) DISULFIDE SHAMPOO (2.5%)

THR: An eye irritant. See also selenium compounds and sulfides. When heated to decomposition it emits very toxic fumes of Se and SO_x .

SELENIUM HEXAFLUORIDE**HR: 3**

CAS: 7783-79-1 NIOSH: VS 9450000
DOT: 2194
mf: F_6Se mw: 192.96

PROP: Colorless gas; mp: -39° (subl -40.6°); bp: -34.5°; d: 3.25 @ -25°.

SYN: SELENIUM FLUORIDE

OSHA PEL: TWA 400 ug/m³
ACGIH TLV: TWA 0.05 ppm
DOT Classification: Poison A

THR: Poison by inhalation. See also selenium compounds and fluorides. When heated to decomposition it emits very toxic fumes of F and Se.

SELENIUM MONOSULFIDE**HR: 3**

CAS: 7446-34-6 NIOSH: VT 0525000
mf: SSe mw: 111.02

PROP: Orange-yellow tablets or powder; mp: 111.03°; bp: decomp @ 118°-119°; d: 3.05 @ 0°.

SYNS: SELENIUM SULFIDE * NCI-C50033

OSHA PEL: TWA 200 ug(Se)/m³

THR: Poison by ingestion. An experimental carcinogen. See also selenium compounds and sulfides. When heated to decomposition it emits very toxic fumes of SO_x and Se.

SELSUN**HR: 2**

NIOSH: VT 2480000

PROP: 2.4% w/v selenium sulfide in aqueous suspension, also contains bentonite, sodium alkyl aryl sulfonate, sodium phosphate, glycerol monoricinoleate, citric acid, captan and perfume.

SYN: NCI-C54546

THR: An eye irritant. See also selenium compounds, bentonite, tri-o-sodium phosphate, citric acid, captan, glycerol monoricinoleate. When heated to decomposition it emits very toxic fumes of Se, SO_x , PO_x , and NO_x .

SEMICARBAZIDE HYDROCHLORIDE**HR: 3**

CAS: 563-41-7 NIOSH: VT 3500000
mf: $CH_5N_3O \cdot ClH$ mw: 111.55

PROP: Prisms from dilute alcohol. Decomps @ 175°-185°; mp: 176° (decomp). Very sol in water; very slightly sol in hot alc; insol in anhydrous ether.

SYNS: AMIDOUREA HYDROCHLORIDE * AMINOUREA HYDROCHLORIDE * CARBAMYLHYDRA-

REFERENCE #40

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

CONTACT REPORT

Meeting: () Telephone: (X) Other: ()

Contact Location: Navajo Nation Minerals Department
Address: P.O. Box 308, Window Rock, Arizona 86515
Person, Title,
Contacted: Rich Koch, Geologist
From: Pat Molloy
Date: April 18, 1989
Subject: Leases - Navajo Lands Uranium Mines

Contact Summary Report:

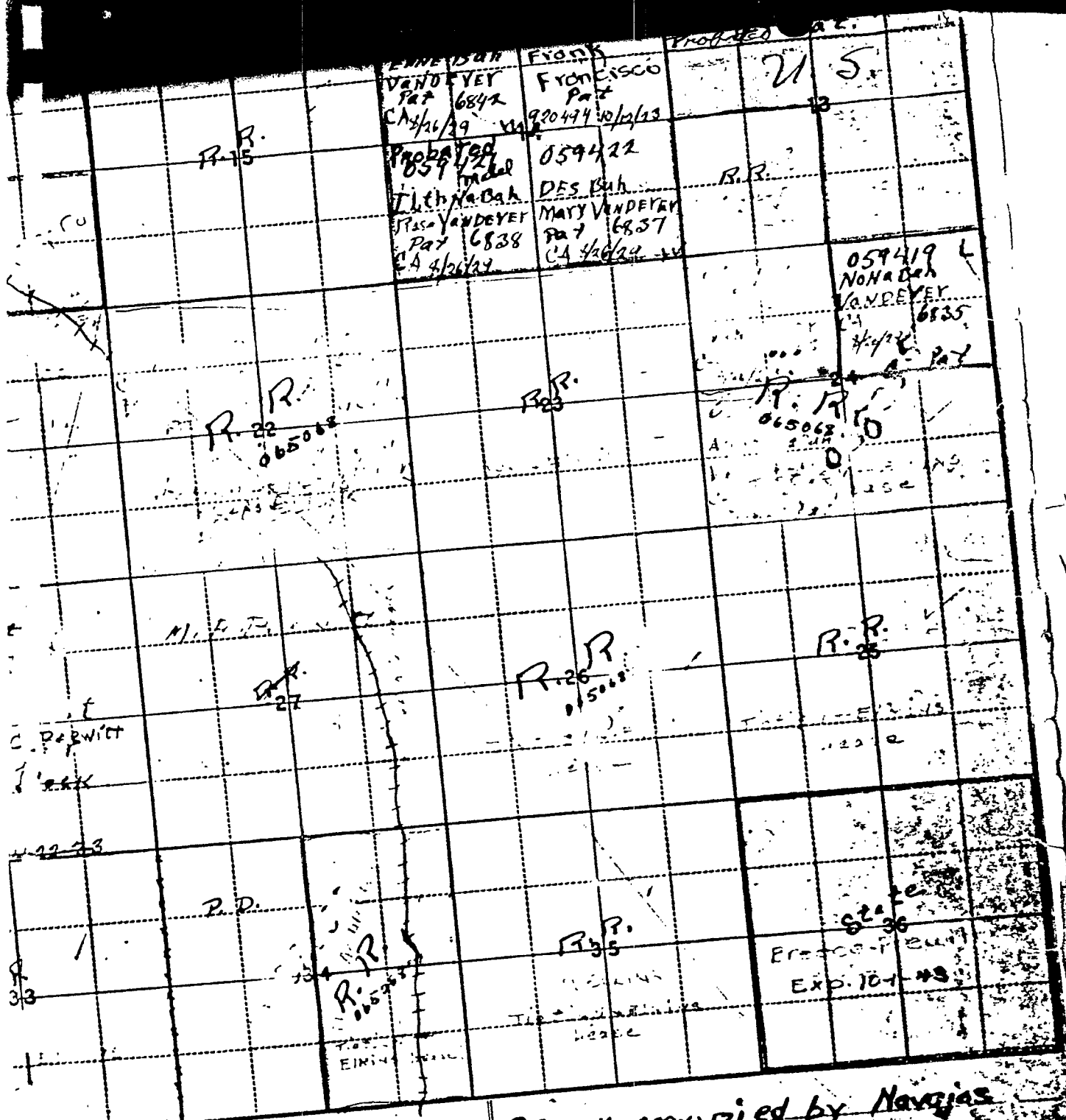
Pre 1960's Uranium Mines -- no records now with tribe. All leases for mines worked before 1960 are presume to be expired.

Minerals department not existence until late 60's. No documents or records on these mines indicating lease holders are in existence with this department.

REFERENCE #41

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90



Sec. 11 occupied by Navajos

065068
 Relinquished to U.S. by R.R. APPR. 6-33
 Sec. 16 lots 1, 2, 3, 4 NE/4, S/2, Sec. 11
 N/4, SE/4 Sec. 13. Minter
 Lien Satisfaction by R.R. Sec. 24
 Sec. 24, Sec. 26. E/2 Sec. 24
 065069 Pat. 18-20-33

REFERENCE #42

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

NAVAJO URANIUM OPERATIONS: EARLY HAZARDS AND RECENT INTERVENTIONS

Harold Tso

Navajo Environmental Protection Commission
Window Rock, Arizona

and

Lora Mangum Shields
Navajo Community College, Shiprock.

ABSTRACT

By 1960, Navajo tribal lands had produced and milled more than six million tons of uranium ore. A total lack of awareness of radiological dangers prevailed during the early days of uranium exploration. Long-lived radioactive wastes became dispersed widely by natural and anthropogenic agents. Continuing radiation hazards remain at three primary man-exposed sources of radioactive products: 1) between 100 and 200 abandoned mine dumps which leach radioactive material to surface and shallow water; 2) mill tailings at four sites retain 85 percent of the radioactivity of the original ore; and 3) three operating mines, two on the reservation and one marginal, discharge on Indian land. Also, water from certain deep wells is contaminated from naturally occurring radioisotopes leached from ore veins by the aquifers. Remedial action on the tailings sites has been initiated. The Navajo Tribal Council identifies the remaining most urgent needs as follows: 1) locate the abandoned mines, 2) reclaim the associated uranium waste piles or dumps, 3) identify contaminated residential quarters, 4) determine the medical history and health status of the occupants and, where indicated, 5) relocate the families.

In 1950, a Navajo Indian, Paddy Martinez, observed yellow coatings on a Todilto limestone outcrop on Santa Fe railroad land. This McKinley County, New Mexico, site was to become the location of the famous Haystack Uranium Mine. It was the richest uranium deposit ever discovered in Todilto limestone. The Santa Fe railroad awarded Paddy Martinez a lifetime annuity of \$250 a month. His find triggered intensified uranium prospecting. Uranium exploration soon expanded into the greatest mining boom since the California goldrush.

The Navajo reservation lies north and west from the major uranium operation at Grants, New Mexico. By 1960, Navajo tribal lands had produced and milled more than six million tons of uranium ore. Uranium mining had begun in the four-corners section of the Navajo reservation in the late 1940's. The population of this northeast quarter of the reservation exceeds 63,400 Navajos. This 1977 figure represents approximately two-fifths of the total

lands. The first regulatory authority over mining operations on the reservation was exercised by the Environmental Protection Agency in the early 1970's. The national congress now is mandating the correction of early radiological abuse of tribal lands. The control of radioactive wastes on the Navajo reservation first must address problems which emerged in two areas as uranium mining developed.

Problem areas.

- 1) A total lack of awareness of radiological dangers prevailed during the early days of uranium explorations. The typical uranium mine in the 1950's was a 3- to 5-man operation. Miners blasted and returned a day or two later when the dust had settled (Tso, 1980). Operators trucked their ore to the mill where the Atomic Energy Commission maintained a buying station. Local contamination was ignored. Long-lived radioactive wastes became dispersed widely by natural and anthropogenic agents.
- 2) Continuing radiation hazards remain at three primary man-exposed sources of radioactive decay products.
 - a) Between 100 and 200 small, shallow (50 ft) uranium deposits on the reservation were mined and abandoned following extraction of the high grade ore. The excavated portion of such mines offers a site for meteoric water impoundment. This impounded water is available for leaching the lower grade uranium ore, transporting dissolved radioactive materials into shallow aquifers and alluvial standing water. Contamination of surface water by mining and milling operations is well documented (EPA, Costle, 1979). Nearly 40 percent of the Navajo families in the surrounding area haul water from shallow wells, stock tanks or springs. The dump material from these mines has remained available for use in construction. A recent radiological scan by the Navajo Environmental Protection Commission has shown high gamma readings in 16 homes in the Oak Springs area, the location of about 50 abandoned mine sites. Their inventory of the 400-500 homes in this vicinity has only begun.
 - b) Tailings in four inactive milling sites have been dispersed widely by wind and water (Schiager, 1974). The crushing, grinding and leaching of ore extracts from 0.1 to 0.5 percent as uranium oxide (U_3O_8) or yellow cake (Wagoner, 1980). The Shiprock tailings retain 85 percent of the natural radioactivity present in uranium ore (Ford *et al.*, 1977).

Until the interim partial reclamation of the 300-acre Shiprock tailings pile, radiation levels were several orders of magnitude greater than the average concentration within the earth's crust (within a mine; Ford *et al.*, 1977). This tailings site is within one mile of a day care center, the public school, the Navajo Junior High School, and the Navajo Community College.

buildings for construction at Aneth read 25,000 alpha counts/min when moved. State regulations prohibit transport at readings above 5,000 counts/min. The greatest hazard from mill tailings, as in the atmosphere of the mine itself, is radon-222, emanated as a gas and transported by the atmosphere. A radon-222 atom in the five days of its mean lifetime could be transported hundreds of miles through the atmosphere, a few feet through the earth or tailings and a few inches through good concrete (Schiager, 1974). Exposure to radon-222 (half-life 3.82 days) and the radon daughters with still shorter half-lives, is measured through bioassay for one of the longer half-lived progeny, lead-210, in food, bone and teeth.

Throughout the uranium belt, mill tailings were used as landfill for building sites until the Nuclear Regulatory Commission prohibited removal around 1976. A 1972 mobile and hand scan survey showed nine buildings in Shiprock with gamma levels of 100-200 μ R/hr at eight sites where tailings were used and 300 μ R/hr for uranium dump material at another site (Pitkin, 1972). These nine high gamma radiation anomalies in Shiprock compare with 101 for Grants, 158 for New Mexico, and 6,253 for Colorado, in general.

- c) Three operating mines, two on the reservation and one marginal, discharge on Indian land. Each of two of these mines employs 350 to 500 workers, most of whom are Navajo.

A dam failed at the off-reservation uranium processing mill in 1979. About 95 million gallons of radioactive water moved into the arroyo bed on Indian land. Contamination carried into tributaries left local hot spots. Tailings were desposited in mud flats and in watering places of grazing animals (Tso, 1980).

To insure optimum safety and acceptance of continued uranium exploration and the use of nuclear energy, we must 1) identify and correct past mistakes and 2) avoid repeating these mistakes in future operations.

Reinterpretation of existing knowledge.

In the reevaluation of existing knowledge, possible unsuspected adverse health effects of low level radiation are emerging. Uranium mining and milling now are recognized as the most significant sources of radiation exposure to the public. The hazards of these two initial steps, primarily from radium-226 and lead-210 (from the radon daughters), surpass by far the later stages in the uranium fuel cycle such as nuclear power reactors and high level radioactive waste disposal (Nuclear Regulatory Commission, 1976). Radiological dangers associated with uranium mining and milling have been severely underestimated. Exposures may affect populations far removed from sources of radioactive material (Sorenson, 1978). Long term, low level exposure may increase the incidence of latent cancers, birth defects and certain forms of mental and physical retardation. The ratio of somatic to genetic effects after a given exposure is 60 times greater than thought 15 years ago (in 1956) (International Commission on Radiological Protection, 1971).

Shiprock was one of '06 communities in the U.S. uranium belt showing elevated radiation levels related to mill tailings (Pitkin, 1972). Shiprock was one of eight of these communities designated for prompt remedial action at federal expense.¹ During 1974-75, however, the Navajo Tribe, assisted by the Environmental Protection Agency and the Indian Health Service, had already conducted an interim stabilization program at the Shiprock site (EPA, Costle, 1978). The tailings had been fenced to restrict access and covered with several feet of soil. This interim cleanup reduced radioactivity in places on the pile to one-fourth of the level before covering and in other places to one-tenth the previous level (Tso, 1980). Before final remedial action, as hauling to a remote site for burial, the Department of Energy must develop engineered disposal plans and prepare an environmental impact statement (Wolff, 1980).

Public Health Service Region IX, with headquarters in San Francisco, monitors environmental quality on the Navajo reservation. The Environmental Protection Agency Environmental Monitoring and Support Laboratory (Las Vegas, Nevada) performs radiological analyses on water samples which Region IX personnel collect from approved sources reservation-wide. Water from unapproved surface sources is not sampled for analysis. Radioactive contamination of certain drilled wells 700-800 ft deep appears to result from naturally occurring radioisotopes leached from ore veins by ground water (HEW, Richmond, 1979). Both the ore and the aquifers frequently occur in the same geological formation. Water from a number of deep known wells exceeds the permissible limit of 3.0 pCi/l radium-226 (double the limit at Martinez Camp, Many Farms, Baca and Smith Lake; above the limit in wells at Thoreau, Rock Point, Rough Rock, and Borrego Pass) (Cumulative Report of Radionuclide Samples on Indian Lands, Region IX, 1979). One well at Martinez Camp has been closed to public use.

The Council for Energy Resource Tribes (CERT), directed by Navajo Tribal Chairman Peter MacDonald, has funded an inventory of tribal lands for abandoned mines and for housing sites which incorporate ore or mill tailings. The Navajo Environmental Protection Commission, Harold Tso, Director, will conduct this survey. The study is designed to "provide accurate and current data to the Tribal Council and its members on the social, economic and cultural effects of resource development" on the Navajo reservation. Specifically, pursuant to the Abandoned Mine Lands Program of PL 95-87, a need exists to 1) establish a computerized data base which designates the locations of abandoned mines on the Navajo reservation; 2) perform radiological surveys in each area to determine the extent of contamination at each mine and in homes in the immediate area; 3) collect samples (air, water, vegetation, stone) and submit for radiological analysis; and 4) assist the tribal Division of Health Improvement Services in determining the health conditions of residents exposed to radioactive substances and in performing medical analyses to determine impacts from mining or uranium processing. Staff at

the Tsaile campus of Navajo Community College will participate in all areas of the study.

The Navajo Tribal Council in a recent resolution recommends identifying and decontaminating abandoned uranium mine sites and filling the mine shafts. The Council recommends, further, that residents of highly radioactive areas be identified and provided with appropriate medical examination and/or care. Already 41 families have been identified.

A separate pending study involving PHS and IHS proposes to evaluate the effect on reproduction of paternal and maternal exposures to radioactive waste (occupational, residential or environmental) in the Shiprock and Red Valley (Cove, Red Rock, Oak Springs) areas.

Another pending project addresses the bioaccumulation of radium-226 and lead-210 in deciduous and adult human teeth and sheep bone from the hip region. Samples for analysis will be secured from populations exposed to mill tailings or to waste uranium ore dumps. The Navajo religious philosophy tends to prohibit the experimental use of human bone. From a single rib obtained in autopsy, however, whole body radium-226 or lead-210 could be extrapolated as Kulp (1961) did for strontium-90. For both radium-226 and lead-210, the access routes to the animal system are through ingestion dissolved or particulate-linked, from water or through plants. Lead-210, in addition, appears transiently in blood and bone and more permanently in teeth following inhalation of radon daughters as from the mine air or emanation from mill tailings.

This project also would survey for radium-226 in soil, water and vegetation. Data for comparison are available from studies (1958-64) along the Animas River downstream from the Durango mill tailings effluent. Radium-226 underwent biomagnification in algae and aquatic bottom insects and appeared in irrigated soils and crops; in livestock, milk and the human population around Farmington, New Mexico (Tsivaglou, 1964). Bioaccumulation of radioisotopes from the Animas River, however, was dismissed as insignificant at the time.

The hazard from uranium mining and milling is primarily from radium-226 and lead-210. Analytical data for radium-226 and lead-210 should each reinforce the other as evidence of the radiological hazard in the environment.

This project also would search IHS/PHS medical records for the area and state tumor registries for the incidence of sarcoma, other bone cancer, lung cancer and leukemia. Agency school records would be examined for evidence of mental retardation and physical defects.

Heart defects appear to have increased in the Shiprock Health Service Unit (Gottlieb, 1980). At Grand Junction, Colorado, where 300,000 tons of tailings disappeared to construction projects, mongolism in the newborn has tripled (Ambler, 1980). Over 200 underground uranium miners have died of lung cancer in the Colorado plateau area (Archer, 1980). Forty percent of the lung cancer patients under recent observation have died before age 40 (Gottlieb, 1980). For population living in the area, the health hazard is

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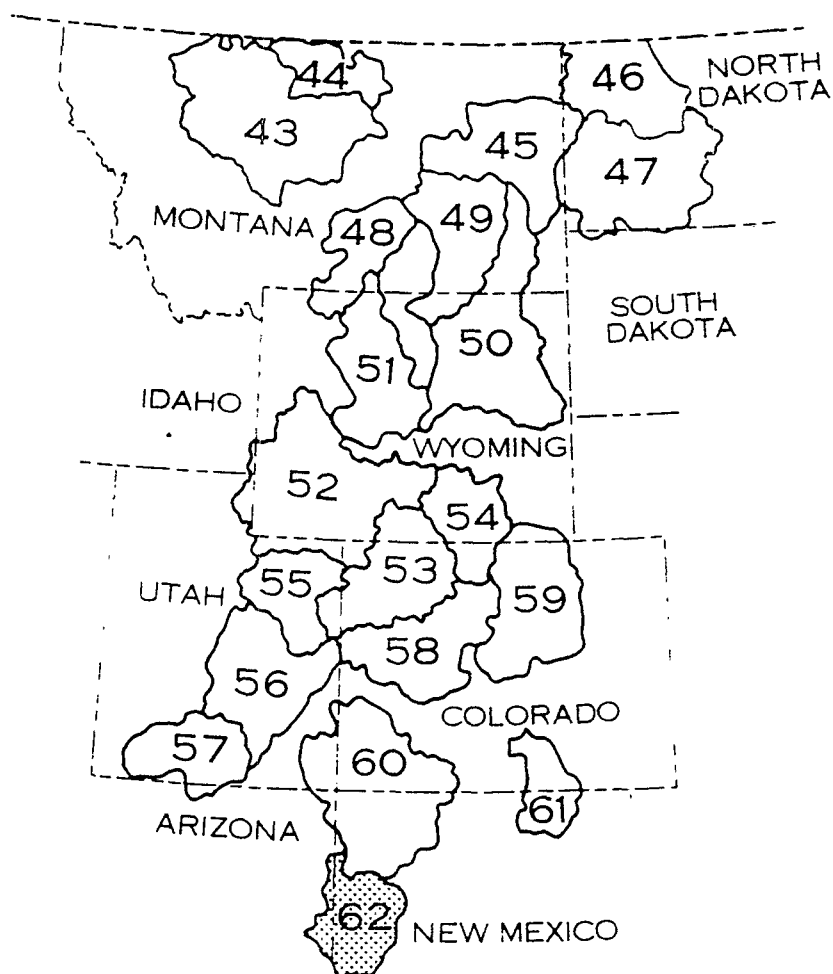
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REFERENCE #43

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

HYDROLOGY OF AREA 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA



- PUERCO RIVER
- ZUNI RIVER
- LARGO CREEK
- CARRIZO WASH
- RIO SAN JOSE
- BLACK CREEK



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-698

HYDROLOGY OF AREA 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA

BY

F. E. ROYBAL, J. G. WELLS, R. L. GOLD, AND J. V. FLAGER

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-698



ALBUQUERQUE, NEW MEXICO
APRIL, 1984

2.0 GENERAL FEATURES--Continued

2.5 Tectonic History

The Major Structural Features of the Coal Area were Largely Developed by Middle Tertiary Time

The major structural features in Area 62 are the southern San Juan Basin, its bounding structures, and the Mogollon slope.

Area 62 lies in the southeastern quarter of the Colorado Plateau, one of the major structural provinces of the United States. The Plateau is characterized by a thick sequence of sedimentary rocks that indicate a long tectonic history (Foster, 1971, p. 363 and Kelley, 1951, p. 124-129). The southern part of the San Juan Basin, its major bounding structures (Kelley, 1951), and the Mogollon slope are the major structural features in Area 62 (fig. 2.5-1).

During the nineteenth century the study of sedimentary rocks and the plant and animal fossils they contained led to the development of the geological time scale (fig. 2.5-2). The scale shows the immensity of time involved for formation of the structural features in Area 62.

The San Juan Basin, a structural embayment of the Colorado Plateau, began to form during a period of uplift as early as Late Paleozoic time (Kelley, 1951, p. 130). The Defiance and Zuni uplifts, the major highland elements in the southern San Juan Basin, were forming in Paleozoic and Mesozoic Time. Kelley states that the present structural elements of the San Juan Basin were probably developed by Middle Tertiary time.

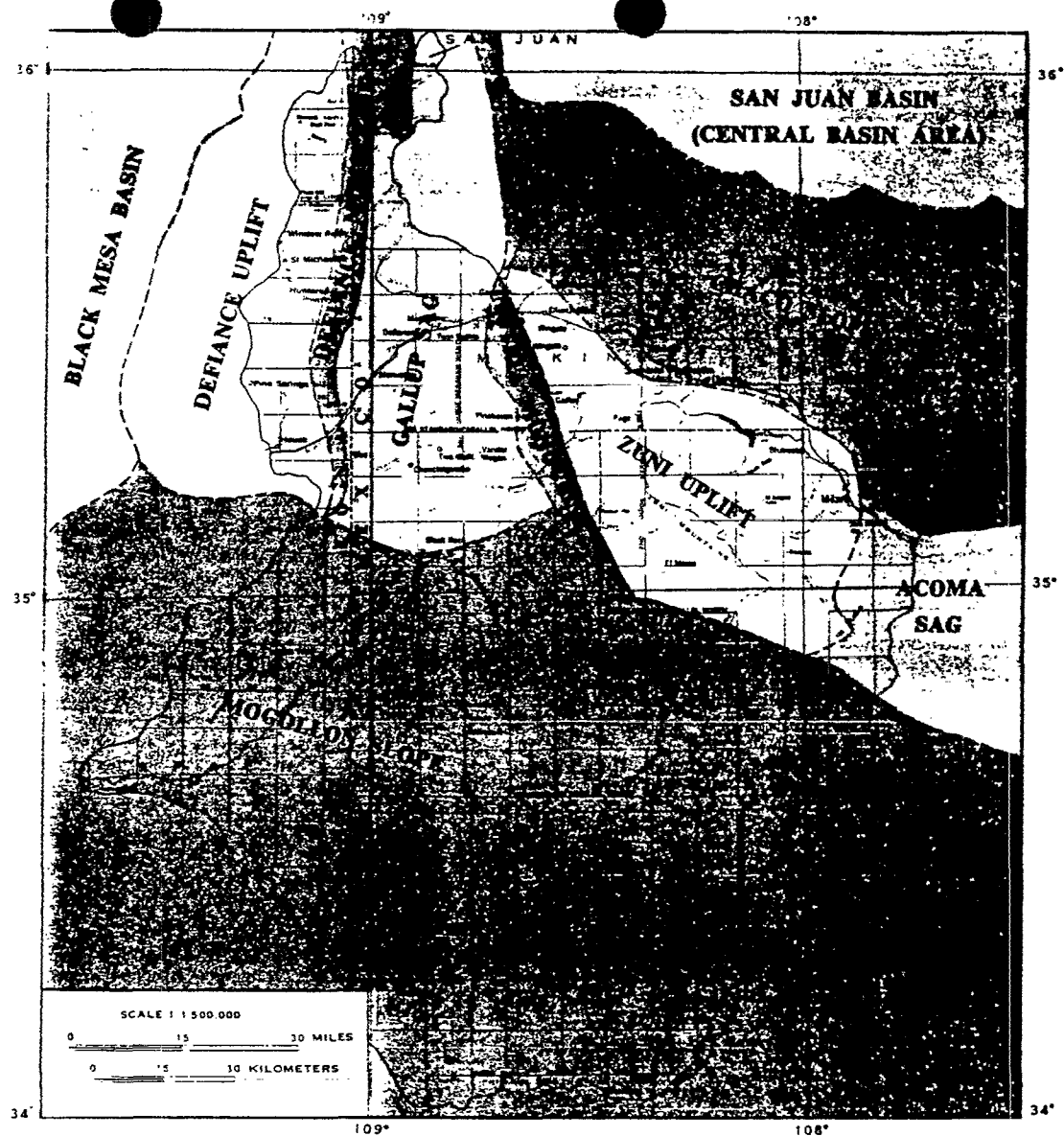
The Mogollon highland dominated the south side of the Colorado Plateau during Late Jurassic time. The south half of the highland (shown in fig. 2.5-1 as the Mogollon slope) was broken and tilted to the northeast during volcanic episodes at the end of the Jurassic Period (Saucier, 1976, p. 152). The Mogollon slope is the structural feature which represents the tectonic remnants of the Mogollon highland.

The Zuni and Defiance uplifts are located on the southern and western edges of the San Juan basin. The Zuni uplift trends northwestward, is 80 miles long by 35 miles wide, and has a structural relief of 5,500 feet (Kelley, 1951, p. 126). The steep limb of the uplift dips southwestward away from the basin. The Defiance uplift trends northward past the study area, is 100 miles long by 30 miles wide, and has a maximum structural relief of 7,500 feet (Kelley, 1967, p. 28). The steep limb dips east toward the San Juan basin (Kelley, 1951).

Two structural platforms (Kelley, 1951, p. 126) are located in the study area: The Acoma sag and the Gallup sag. The Acoma sag is a flat wide area bordering the Zuni uplift on the east. The Gallup sag extends from the San Juan basin southward between the Defiance and Zuni uplifts (Kelley, 1967, p. 29).

Two monoclines border the Gallup sag. The Nutria Monocline bounds the north two-thirds of the Zuni uplift on its west side (Kelley, 1967) and the Defiance monocline borders the Defiance uplift on its east side.

Kelley (1951, p. 126) describes the Chaco slope as the southern part of the San Juan Basin that lies between the Central Basin (fig. 2.5-1) and the Zuni uplift and Acoma sag. The Chaco slope resembles the platforms but differs from them because of "its more pronounced and continuous regional inclination toward the center of the basin and by the absence of a 'monocline' separating it from the Central Basin" (Kelley, 1951, p. 126).



Structural features modified
from Kelley (1951, 1955)

EXPLANATION





-  UPLIFTS
-  BASINS AND PLATFORMS
-  SLOPES AND MONOCLINES
-  BOUNDARY BETWEEN STRUCTURAL FEATURES

Figure 2.5-1 Major structural features.

REFERENCE #44

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

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PARTS 190 to 399

Revised as of July 1, 1987

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T. MORRIS JUNE '90

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CONTACT LOCATION: NSO

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Pat Molloy, Health Physicist, NSO

PHONE: 602-871-7332

FROM (Contacting

party): T. Morris, Environmental Spec., NSO

DATE: 6/18/90

SUBJECT: Calculations: Nanabah Vandever Waste Piles Radon Emissions

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

See Attached:

1. Assume that the near tailings pile is 30% of the volume of the larger tailings pile, then

$$\begin{aligned} V_{TP}^{(1)} + V_{TP}^{(2)} &= 1.3 V_{TP}^{(1)} \\ &= 1.3 [9.94 (10^5) \text{ ft}^3] \\ V'_{TP} &= 1.29 (10^6) \text{ ft}^3. \end{aligned}$$

2. Assume that the fraction of U_3O_8 within the tailings is of the order of magnitude of 10^{-4} whereby,

$$\begin{aligned} VU_3O_8 &= 10^{-4} V'_{TP} \\ &= 1.29 (10^2) \text{ ft}^3 \\ &= 3.66 (10^6) \text{ cm}^3 \end{aligned}$$

3. Compute the mass and weight of U_3O_8

$$\begin{aligned} MU_3O_8 &= 23.26 \text{ gm} \cdot \text{cm}^{-3} [3.66(10^6) \text{ cm}^3] \\ &= 8.5 (10^4) \text{ kg} \\ &: 93.7 \text{ Tons} \end{aligned}$$

4. Assume that only the upper 3 meters of tailings contributes to the area Radon burden (NOTE: $\tanh(\lambda \times D_t) \approx 0.999$)

$$\begin{aligned} J_t &= 10^4 \text{ RPE} (D_t)^{\frac{1}{2}} \tanh [(\lambda D_t^{-1})^{\frac{1}{2}} x_t] \\ &= 352.3 \text{ pCi} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \end{aligned}$$

5. Compute the Flux rate for the "Horizontal" surface area as

$$\begin{aligned} J_t A_t &= (352.3) (659.6) \text{ pCi} \cdot \text{s}^{-1} \\ &= 2.32 (10^5) \text{ pCi} \cdot \text{s}^{-1}, \end{aligned}$$

$$\text{Where } 659.6 \text{ m}^2 = 7.1 (10^3) \text{ ft}^2.$$

6. Compute the yearly Radon production as

$$\begin{aligned} J_t A_t AT_{yr} &= [2.32(10^5)](60)^2(365)(24) \\ &= 7.33 \text{ Curies} \end{aligned}$$

7. Compare the above quantity with the calculation using the

value of $(10^3 \text{ pCi} \cdot \text{m}^{-2} \cdot \text{s}^{-1}) \times (.22)$ (for aged tailings)

$$(.22) (10^3) (659.6) (60)^2 (365) (24)$$

$$= 4.58 \text{ Curies}$$

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PARTS 190 TO 399
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NAVAJO SUPERFUND OFFICE
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WINDOW ROCK, AZ. 86515



PART 192—HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM AND THORIUM MILL TAILINGS

Subpart A—Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites

Sec.

- 192.00 Applicability.
192.01 Definitions.
192.02 Standards.

Subpart B—Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

- 192.10 Applicability.
192.11 Definitions.
192.12 Standards.

Subpart C—Implementation

- 192.20 Guidance for implementation.
192.21 Criteria for applying supplemental standards.
192.22 Supplemental standards.
192.23 Effective date.

Subpart D—Standards for Management of Uranium Byproduct Materials Pursuant to Section 84 of the Atomic Energy Act of 1954, as Amended

- 192.30 Applicability.
192.31 Definitions and cross-references.
192.32 Standards.
192.33 Corrective action programs.
192.34 Effective date.

TABLE A TO SUBPART D

Subpart E—Standards for Management of Thorium Byproduct Materials Pursuant to Section 84 of the Atomic Energy Act of 1954, as Amended

- 192.40 Applicability.
192.41 Provisions.
192.42 Substitute provisions.
192.43 Effective date.

AUTHORITY: Sec. 275 of the Atomic Energy Act of 1954, 42 U.S.C. 2022, as added by the Uranium Mill Tailings Radiation Control Act of 1978, Pub. L. 95-604, as amended.

SOURCE: 48 FR 602, Jan. 5, 1983, unless otherwise noted.

Subpart A—Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites

§ 192.00 Applicability.

This subpart applies to the control of residual radioactive material at designated processing or depository sites under section 108 of the Uranium Mill Tailings Radiation Control Act of 1978 (henceforth designated "the Act"), and to restoration of such sites following any use of subsurface minerals under section 104(h) of the Act.

§ 192.01 Definitions.

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as in Title I of the Act.

(b) *Remedial* action means any action performed under section 108 of the Act.

(c) *Control* means any remedial action intended to stabilize, inhibit future misuse of, or reduce emissions or effluents from residual radioactive materials.

(d) *Disposal site* means the region within the smallest perimeter of residual radioactive material (excluding cover materials) following completion of control activities.

(e) *Depository site* means a disposal site (other than a processing site) selected under section 104(b) or 105(b) of the Act.

(f) *Curie (Ci)* means the amount of radioactive material that produces 37 billion nuclear transformation per second. One picocurie (pCi) = 10^{-12} Ci.

§ 192.02 Standards.

Control shall be designed¹ to:

(a) Be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and,

(b) Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not.

¹ Because the standard applies to design, monitoring after disposal is not required to demonstrate compliance.

(1) Exceed an average² release rate of 20 picocuries per square meter per second, or

(2) Increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter.

Subpart B—Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

§ 192.10 Applicability.

This subpart applies to land and buildings that are part of any processing site designated by the Secretary of Energy under section 102 of the Act, section 101 of the Act, states, in part, that "processing site" means—

(a) Any site, including the mill, containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to any Federal agency prior to January 1, 1971, under a contract with any Federal agency, except in the case of a site at or near Slick Rock, Colorado, unless—

(1) Such site was owned or controlled as of January 1, 1978, or is thereafter owned or controlled, by any Federal agency, or

(2) A license (issued by the (Nuclear Regulatory) Commission or its predecessor agency under the Atomic Energy Act of 1954 or by a State as permitted under section 274 of such Act) for the production at site of any uranium or thorium product derived from ores is in effect on January 1, 1978, or is issued or renewed after such date; and

² This average shall apply over the entire surface of the disposal site and over at least a one-year period. Radon will come from both residual radioactive materials and from materials covering them. Radon emissions from the covering materials should be estimated as part of developing a remedial action plan for each site. The standard, however, applies only to emissions from residual radioactive materials to the atmosphere.

§ 192.11

(b) Any other real property or improvement thereon which—

- (1) Is in the vicinity of such site, and
- (2) Is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

§ 192.11 Definitions.

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Act or in Subpart A.

(b) "Land" means any surface or subsurface land that is not part of a disposal site and is not covered by an occupiable building.

(c) "Working Level" (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

(d) "Soil" means all unconsolidated materials normally found on or near the surface of the earth including, but not limited to, silts, clays, sands, gravel, and small rocks.

§ 192.12 Standards.

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

(a) The concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than—

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and

(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.

(b) In any occupied or habitable building—

(1) The objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

(2) The level of gamma radiation shall not exceed the background level

40 CFR Ch. I (7-1-87 Edition)

by more than 20 microroentgens per hour.

Subpart C—Implementation

§ 192.20 Guidance for implementation.

Section 108 of the Act requires the Secretary of Energy to select and perform remedial actions with the concurrence of the Nuclear Regulatory Commission and the full participation of any State that pays part of the cost, and in consultation, as appropriate, with affected Indian Tribes and the Secretary of the Interior. These parties, in their respective roles under section 108, are referred to hereafter as "the implementing agencies." The implementing agencies shall establish methods and procedures to provide "reasonable assurance" that the provisions of Subparts A and B are satisfied. This should be done as appropriate through use of analytic models and site-specific analyses, in the case of Subpart A, and for Subpart B through measurements performed within the accuracy of currently available types of field and laboratory instruments in conjunction with reasonable survey and sampling procedures. These methods and procedures may be varied to suit conditions at specific sites. In particular:

(a)(1) The purpose of Subpart A is to provide for long-term stabilization and isolation in order to inhibit misuse and spreading of residual radioactive materials, control releases of radon to air, and protect water. Subpart A may be implemented through analysis of the physical properties of the site and the control system and projection of the effects of natural processes over time. Events and processes that could significantly affect the average radon release rate from the entire disposal site should be considered. Phenomena that are localized or temporary, such as local cracking or burrowing of rodents, need to be taken into account only if their cumulative effect would be significant in determining compliance with the standard. Computational models, theories, and prevalent expert judgment may be used to decide that a control system design will satisfy the standard. The numerical range provid-

Environmental Protection Agency

ed in the standard for the longevity of the effectiveness of the control of residual radioactive materials allows for consideration of the various factors affecting the longevity of control and stabilization methods and their costs. These factors have different levels of predictability and may vary for the different sites.

(2) Protection of water should be considered in the analysis for reasonable assurance of compliance with the provisions of § 192.02. Protection of water should be considered on a case-specific basis, drawing on hydrological and geochemical surveys and all other relevant data. The hydrologic and geologic assessment to be conducted at each site should include a monitoring program sufficient to establish background ground water quality through one or more upgradient wells, and identify the presence and movement of plumes associated with the tailings piles.

(3) If contaminants have been released from a tailings pile, an assessment of the location of the contaminants and the rate and direction of movement of contaminated ground water, as well as its relative contamination should be made. In addition the assessment should identify the attenuative capacity of the unsaturated and saturated zone to determine the extent of plume movement. Judgments on the possible need for remedial or protective actions for groundwater aquifers should be guided by relevant considerations described in EPA hazardous waste management system (47 FR 32274, July 26, 1982) and by relevant State and Federal Water Quality Criteria for anticipated or existing uses of water over the term of the stabilization. The decision on whether to institute remedial action, what specific action to take, and what levels an aquifer should be protected or restored should be made on a case-by-case basis taking into account such factors as technical feasibility, improving the aquifer in its hydrologic setting, the cost of applicable restorative or protective programs, the present and future value of the aquifer as a water resource, the availability of alternative water supplies, and

REFERENCE #47

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT

Meeting: ()

Telephone: (X)

Other: ()

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ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Mike BuMvond, Geologist, New Mexico Abandoned Mine Lands

PHONE: 505-827-5970

FROM (Contacting

party): Tom Morris, Environmental Specialist, Navajo Superfund Office

DATE: 6/19/90

SUBJECT: Abandoned Uranium Mines, Haystack Mountain, NM

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

No inventory or studies have been conducted for the Haystack area, and none are planned for the future. The NMAML was not aware of the abandoned Uranium mines at Haystack Mountain. The New Mexico Office of Surface Mining is believed to have jurisdiction over the abandoned mines on Indian Allotment Lands.

REFERENCE #48

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS

JUNE '90

CONTACT REPORT

Meeting: ()

Telephone: (x)

Other: ()

CONTACT LOCATION: Navajo Superfund Office

ADDRESS: P.O.B. 2946, Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Martin Begay, Director, Navajo Abandoned Mine Lands

PHONE: 602-729-2294

FROM (Contacting

party): Tom Morris, Environmental Specialist, Navajo Superfund Office

DATE: 6/23/90

SUBJECT: Abandoned Mine Lands, Haystack Mountain, NM

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

The Navajo AML has done no surveys of the Haystack Mountain area, and claims no jurisdiction in relation to Indian allotment lands.

REFERENCE #49

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

URANIUM IN THE SAN JUAN BASIN—AN OVERVIEW*

WILLIAM L. CHENOWETH

U.S. Energy Research and Development Administration
Grand Junction, Colorado

INTRODUCTION

The San Juan Basin of northwest New Mexico has been the source of more uranium production than any other area in the United States. Nearly all of the production has come from the Grants mineral belt (fig. 1). This paper describes the geologic setting of the ore deposits in the San Juan Basin, summarizes the growth of the uranium raw materials industry, and reviews the resource base.

GEOLOGIC SETTING

In the San Juan Basin, bedded and vein uranium deposits are in several different rock-types of Mesozoic and Tertiary age. Tabular deposits, which occur primarily in continental, fluvial sandstone of Jurassic age, are the most important. Only the more significant occurrences are discussed in this paper.

Most uranium deposits are in the Grants mineral belt in McKinley, Sandoval and Valencia counties. This cluster of large deposits extends for nearly 100 miles across the southern flank of the San Juan Basin. Although poorly defined, the belt is 10 to 20 miles wide. The four principal mining areas in the belt are Gallup, Smith Lake, Ambrosia Lake and Laguna (fig. 1). Ore deposits occur from the surface to depths greater than 4,000 feet, although to date all production has come from deposits shallower than 2,000 feet. Deposits in the Grants mineral belt have been described in detail by Kelley (1963) and by Hilpert (1969).

The Todilto Limestone of Jurassic age contains uranium ore bodies along the southern margin of the Grants mineral belt, where the limestone has been deformed by intraformational folding and faulting. Some 2,718 tons of U_3O_8 have been produced from 42 properties, mainly in the Ambrosia Lake area, accounting for two percent of the total output of the mineral belt. At a few places in the Todilto, ore also has been mined from the underlying Entrada Sandstone of Jurassic age where the ore bodies cross the contact between the two formations. Uranium also occurs in the Todilto in the Sanostee area of San Juan County, where small trial shipments have been made from two properties.

The Morrison Formation of Jurassic age was deposited in a continental environment. It consists of interbedded fluvial sandstone, claystone and mudstone. In the southern San Juan Basin, the Morrison consists of three members, all of which contain ore deposits. In ascending order, they are the Recapture, Westwater Canyon and Brushy Basin members. In the Ambrosia Lake and Laguna areas, the Recapture contains minor sandstone beds that are hosts for small uranium deposits.

The Westwater Canyon Member consists of thick sandstones with interbedded lenses of relatively thin discontinuous claystone. This member contains large uranium deposits in the Ambrosia Lake and Gallup areas. The Brushy Basin Member consists of greenish-gray mudstone and claystone with in-

terbedded sandstone and a few thin beds of limestone. A thick lens of sandstone, the Jackpile sandstone, occurs in the upper part of the Brushy Basin in the Laguna area, where it contains large ore deposits. The Brushy Basin also is host for deposits in the Smith Lake area, although these are smaller than those at Laguna.

Uranium deposits of the Grants mineral belt are irregular in shape and generally are parallel to paleostream channels (fig. 2). The deposits range in size from thin pods a few feet in width and length to large masses of ore several thousand feet long, several hundred feet wide and several tens of feet thick.

The deposits are in many different sandstone beds and form clusters along distinct trends. Some ore has been redistributed, generally in areas of faulting (fig. 3). The principal ore mineral in the Grants sandstone deposits is coffinite, a uranium silicate ($U(SiO_4)_1 - x(OH)_{4x}$), which is intimately associated with grayish-black to brown carbonaceous humate, which impregnates the sandstone. Production from the Morrison Formation in the Grants mineral belt has amounted to 114,795 tons U_3O_8 .

In the northwestern San Juan Basin, uranium-vanadium deposits occur in the Salt Wash Member of the Morrison Formation on the eastern side of the Carrizo Mountains. This member, composed of interbedded mudstones and fluvial sandstones, is the lowermost member of the Morrison and is present nowhere else in the basin. Mines in the eastern Carrizo Mountains, astride the New Mexico-Arizona line, have produced 110 tons U_3O_8 .

South of the Carrizo Mountains, in the Chuska Mountains near Sanostee, both the Salt Wash and Recapture members have yielded ore. Sandstones in the Recapture have been the most productive host rock, from which 80 tons of U_3O_8 have been obtained.

On the eastern flank of the San Juan Basin, the Morrison Formation has yielded 395 tons of ore, averaging 0.13 percent U_3O_8 , from two properties on the Ojo del Espiritu Santo Grant, northwest of San Ysidro.

The Dakota Sandstone of Cretaceous age has yielded 246 tons of U_3O_8 from nine properties in the Gallup and Ambrosia Lake areas. The Dakota host rocks are carbonaceous sandstone, carbonaceous shale and lignite. On the eastern flank of the basin, south of Cuba, New Mexico, 23 tons containing 0.63 percent U_3O_8 , have been mined from carbonaceous shale and lignite at one property in the Dakota Sandstone.

Uranium occurs in rocks of the Mesaverde Group of Cretaceous age, at various locations in the San Juan Basin. The most significant area is near La Ventana on the eastern flank of the basin. Here, uranium-bearing coal, carbonaceous shale and carbonaceous sandstone form a mineralized zone several feet thick in the upper part of the Menefee Formation immediately below the La Ventana Tongue. Studies by Bachman and others (1959), suggest that a resource of 132,000 tons, averaging 0.10 percent uranium is present; principally on North Butte.

A small amount of ore has been produced from a sandstone

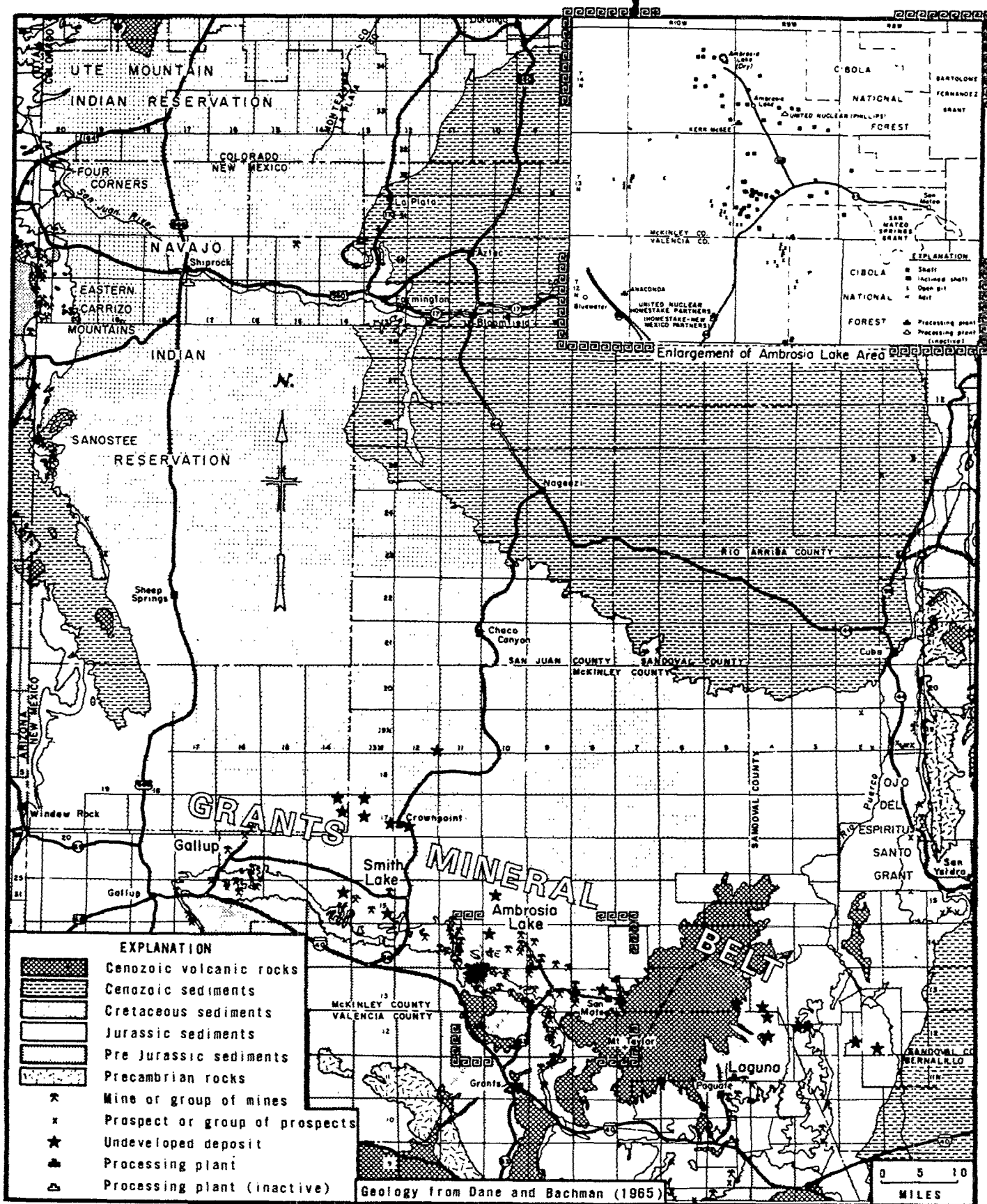


Figure 1. Uranium occurrences, mines and mills, San Juan Basin.

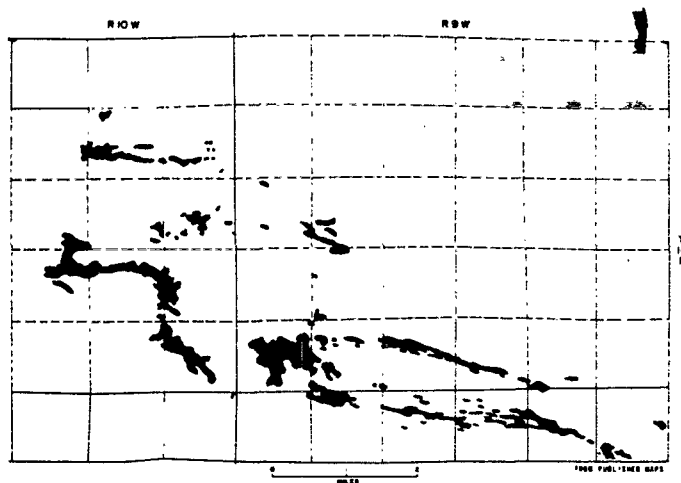


Figure 2. Plan map of ore bodies, Ambrosia Lake area.

in the lower part of the Fruitland Formation of Cretaceous age, northwest of Farmington.

The Ojo Alamo Sandstone of Paleocene age and the San Jose Formation of Eocene age contain uranium in Rio Arriba and San Juan counties. To date, no commercial deposits have been developed.

In the San Juan Basin, vein-type deposits occur in collapsed pipe structures in the mineral belt. The most significant structure is that exploited by the Woodrow mine, north of Laguna. This mine yielded 67 tons U_3O_8 during the middle 1950s.

HISTORY OF EXPLORATION

The first significant discovery of uranium in the San Juan Basin was in vanadium-bearing carnotite ores in the eastern Carrizo Mountains west of Shiprock by John Wade in 1918. By 1920, Wade had 41 claims in various parts of the Carrizo Mountains (personal communication, 1955), including the eastern flank. No ore was mined then, due to lack of demand for either vanadium or uranium.

One of the earliest observations of uranium minerals in the Grants area was made in 1937 when V. C. Kelley (1963, p. 1) noted carnotite in a hand specimen which had been collected by Mr. Whiteside, a local prospector. Since Kelley's observation was unrecorded, the occurrence of uranium minerals of the Grants area was overlooked for many years.

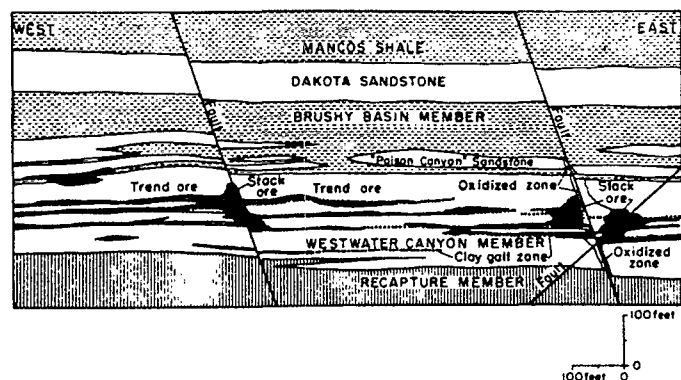


Figure 3. Generalized cross section through ore bodies, Ambrosia Lake area.

World War II increased the demand for vanadium. Early in 1942, Wade, Curran and Company leased a few plots in the east Carrizos. In July 1942, the Vanadium Corporation of America (VCA) leased 12 plots in the east Carrizo area. From 1942 to 1944, these two companies mined carnotite ore from surface exposures in the Salt Wash Member of the Morrison Formation. Although these ores were mined for their vanadium content, uranium was later recovered from the mill tailings. Following the termination of vanadium mining in 1944, the Union Mines Development Corporation systematically studied the vanadium-uranium deposits in the Morrison Formation in the Carrizo Mountains as part of a general uranium resource appraisal of the Colorado Plateau by the federal government's Manhattan Engineer District. Their work was very thorough and few surface exposures of uranium known today were overlooked. Coleman (1944) and Webber (1947) of Union Mines estimated the early ore production for the eastern Carrizo Mountains as 12,000 tons, averaging 0.27 percent U_3O_8 and 3.00 percent V_2O_5 .

In 1948, prospecting for uranium was stimulated by the ore-buying schedules and other incentives of the U.S. Atomic Energy Commission (AEC). In the years that followed, uranium deposits were discovered in the Sanostee area, south of the Carrizo Mountains, and in the Cuba-San Ysidro area on the eastern side of the basin. The well publicized uranium discovery by Paddy Martinez in the Todilto Limestone near Haystack Butte in Valencia County in the fall of 1950 brought a wave of prospectors into the Grants area. In January 1951, uranium was discovered nearby in the Morrison Formation in Poison Canyon. This discovery led to the subsequent delineation of the Poison Canyon trend deposits. In November 1951, an airborne radioactive anomaly was detected north of Laguna in Valencia County, by the Anaconda Copper Mining Company, which led to the development of the Jackpile mine. Prospecting continued throughout the San Juan Basin, and by 1956 all surface occurrences had been discovered.

Using the cuttings of an oil well on the nearby Ambrosia dome to ascertain the drilling depths to the Morrison Formation, Louis Lothman began a wildcat uranium drilling project in April 1955, in sec. 11, T. 14 N., R. 10 W. (Louis Lothman, 1956, written communication). The second hole penetrated uranium-bearing sandstone in the Westwater Canyon Member. The discovery stimulated an intensive exploration effort and led to eventual development of the multi-million-ton deposits in the Ambrosia Lake area.

During the extensive prospecting that followed the initial discoveries in the Grants area in late 1951 and early 1952, several small ore bodies were discovered in outcrops of the Morrison and Dakota formations in the Gallup and Thoreau areas. Drilling down dip from these deposits led to the discovery of the larger Blackjack and Church Rock ore bodies in 1958 by the Lance Corporation and Phillips Petroleum, respectively.

In 1962, an ore body was found by Sabre Pinon Corporation in the northeast Church Rock area, where previous drilling had penetrated ore-grade material at a depth of about 1,875 feet in the Westwater Canyon Member. Exploration by Kerr-McGee on adjacent Navajo Tribal lands led to the discovery of its northeast Church Rock ore body in 1966. Following the competitive sale of Navajo leases in 1971, exploration efforts have continued in the northeast Church Rock area and have been extended eastward into the Crownpoint area, where large

ore bodies are currently being developed by several companies.

The discovery of ore at a depth of 2,700 feet in the Westwater Canyon Member near San Mateo by the Fernandez Joint Venture in the fall of 1968, led to the eastward extension of the Ambrosia Lake area. Nearly a year later, ore-grade intercepts were found at a depth of 4,000 feet in a hole drilled by the Bokum Corporation on the flanks of Mt. Taylor. By early 1971, Gulf Oil had purchased the San Mateo and Mt. Taylor ore bodies to consolidate its holdings in the east Ambrosia area. At about the same time, exploration on the eastern side of Mt. Taylor, especially in the Marquez area, identified ore in the Westwater Canyon Member in an area previously explored only for ore in the Jackpile sandstone of the overlying Brushy Basin Member. In August 1976, Continental Oil Company announced a major find at the extreme eastern end of the mineral belt on the Bernabe Montano Grant.

In January 1974, the Exxon Company signed an agreement with the Navajo Tribe to explore 400,000 acres of tribal land in the western San Juan Basin. This agreement was approved by the Secretary of the Interior in January 1977. As a part of the agreement, the Navajo Tribe received a \$6,327,300 bonus from Exxon.

In December 1975, the Phillips Petroleum Company announced the discovery of a large deposit, approximately 25 million pounds U_3O_8 , 12 miles north of Crownpoint in McKinley County at depths of 3,000 to 3,500 feet. Since this discovery is considerably north of the present concept of the Grants mineral belt, it has revived deeper exploration in the San Juan Basin.

The Mobil Oil Corporation entered into an exploration agreement with the Ute Mountain Tribe in January 1976, for uranium exploration on 162,176 acres of tribal land in south-western Colorado. This agreement brought the Ute Mountain Tribe a bonus of \$2,432,640.

The magnitude of the exploration efforts expended in the San Juan Basin can be measured by the amount of surface drilling that has taken place. Records of ERDA's Grand Junction

Office show that from 1964 to 1977, there were 12,622 holes, having a total footage of 16,002,368 feet, drilled in the search for new deposits. In addition, 10,991 holes having a total footage of 13,059,300 feet were drilled for the development of deposits. The San Juan Basin had its peak year in 1976 when 7,104 holes having a total footage of 10,916,302 feet were drilled. This footage represents 32 percent of the total U.S. surface drilling for uranium in 1976.

PRODUCTION

ERDA records indicate that during 1948-1976, the San Juan Basin produced 55,649,500 tons of ore averaging 0.21 percent U_3O_8 , and containing 118,018 tons U_3O_8 . In addition, 1,145 tons U_3O_8 have been recovered from mine water. These totals constitute 40 percent of the domestic production through 1976. Details of this production are summarized in Table 1. The most productive area is Ambrosia Lake, where the mines, shown in Figure 2, have produced 62,760 tons U_3O_8 or 53 percent of the basin's total production.

When AEC buying schedules for uranium went into effect in 1948, mining commenced in the King Tuttle Mesa area of the eastern Carrizo Mountains and uranium production in the San Juan Basin began. The yearly production is shown graphically in Figure 4.

As the mines in the Ambrosia Lake area came into production, the amount of uranium ore produced increased rapidly (fig. 4). Production reached an all-time high of slightly more than 7,900 tons of U_3O_8 in 1962, but declined sharply in 1963 during the AEC's stretchout program. This program, announced November 17, 1962, extended the government's procurement program from January 1, 1967, to December 31, 1970. It deferred delivery to 1967 and 1968 of some uranium concentrates which were originally contracted for delivery before 1967, and provided for purchase of additional amounts of concentrates in 1969 and 1970 equal to the amounts deferred to 1967 and 1968.

Since January 1, 1971, when the AEC ceased its procurement program, most uranium purchases have been made by

Table 1. Summary of uranium production, San Juan Basin.

Area and Source	Member	Number Of Properties	Type Of Mines	Years Of Production	Production Tons U ₃ O ₈	Remarks
Grants Mineral Belt						
Morrison Formation	Westwater Canyon, Brushy Basin, and Peralta	29	Underground, Two large open pits	1951 to present	114,795	Molybdenum and vanadium recovered as by products
Tortito Limestone	"	42	Underground and open pit	1951 to present	2,718	
Juventa Sandstone	"	3	Underground	1951 thru 1976	246	
Mine water	"	"	"	1963 to present	1,145	
Brucina Limestone	"	1	Underground	1953 thru 1956	67	
East Carrizo Mountains						
Morrison Formation	Griffith	45	Underground	1948 thru 1968	110	1,141 tons U_3O_8 produced as a by product
Sanostee						
Morrison Formation	Sanostee, and San Mateo	11	Underground	1951 thru 1971, 1976	81	
Tortito Limestone	"	1	Open pit	1952		
Nacimiento						
Morrison Formation	"	2	Open pit	1952 thru 1956		
Juventa Sandstone	"	1	Open pit	1954 thru 1957		
Farmington						
Brucina Limestone	"	1	Open pit	1955		
TOTAL					119,183	

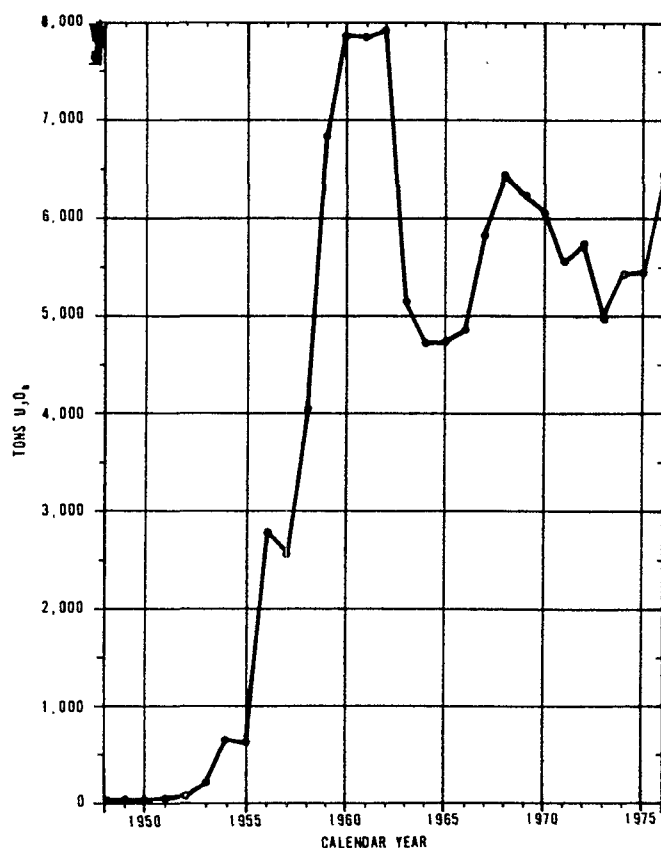


Figure 4. San Juan Basin uranium production, 1948 through 1976.

the nuclear electrical power industry. The decline in uranium sales in the early 1970s was due to a saturated market and was accentuated in 1973 by a long strike against Kerr-McGee. The rise in production in recent years reflects increased demand by the electric-power utility companies.

Recent large increases in spot prices being paid for uranium have had little effect on the production in the Grants mineral belt during 1976. In a recent survey by ERDA, U.S. producers reported that the prices for uranium delivered in 1976 ranged from slightly over \$6 to nearly \$42 per pound. The average price of uranium reported for actual deliveries in 1976 was \$16.10 per pound. This is due to the fact that most of the current production is tied to long-term contracts that were negotiated before the sharp rise occurred. The price of uranium sold by the producers in the Grants area in 1976 probably is near the national average.

PROCESSING FACILITIES

Early output from the eastern Carrizo Mountains was shipped to the Vanadium Corporation of America's (VCA) mill at Durango, Colorado. Shipments continued to the Durango mill until it closed in March 1963. In January 1952, the AEC opened an ore-buying station at Shiprock, New Mexico, and closed it in 1954 when Kerr-McGee Oil Industries began operating a mill at Shiprock. Although this mill was built to treat ore from the Lukachukai Mountains in north-eastern Arizona, it also treated ore from non-VCA properties in the eastern Carrizo Mountains. VCA acquired the Shiprock mill in March 1963, and operated it until it closed in 1968.

At first, limestone and sandstone ores from the Grants area were shipped to the AEC buying station at Monticello, Utah. In June 1952, an AEC buying station was established at Bluewater, New Mexico, and closed when the Anaconda mill went on-stream at Bluewater in mid-1958. This mill, using a carbonate-leaching circuit, was constructed to treat limestone ores and operated until May 1959. In 1955, Anaconda constructed a second mill to treat sandstone ores derived chiefly from its Jackpile mine.

Following the discovery of the Ambrosia Lake ore bodies, the AEC established a buying station at Milan, New Mexico, in mid-1956. In late-1956, the AEC contracted to purchase uranium concentrate from Homestake-New Mexico Partners. During 1957, additional purchase contracts were signed with Homestake-Sapin Partners, Kermac Nuclear Fuels and Phillips Petroleum Company. The four uranium mills required to fulfill these contracts began operating in 1958.

After the consolidation of the two Homestake mills in November 1961, the Homestake-New Mexico Partners mill was shut down in April 1962. When Phillips sold its interests to United Nuclear Corporation in March 1963, the Phillips mill was shut down and United Nuclear began shipping its ore for processing, on a toll basis, to the Homestake-Sapin Partners' mill. This is the only remaining carbonate-leach mill in the Grants area, and it is now operated by United Nuclear in partnership with Homestake Mining Company.

In 1973, Sohio Petroleum Company and Reserve Oil and Minerals Corporation announced their intention to build a 1,600-tons-per-day mill on their property near Cebolleta, New Mexico. Construction of this facility began in 1974, and the mill became operational in August 1976.

In early 1977, the four mills operating in New Mexico had a combined nominal operating capacity of 15,100 tons of ore per day, which is nearly half of the total daily national capacity. These mills and operating capacities are as follows:

	Tons of Ore Per Day
The Anaconda Company	3,000
Kerr-McGee Nuclear Corporation	7,000
Sohio Petroleum Co.-Reserve Oil and Minerals Corp.	1,600
United Nuclear-Homestake Partners	3,500
Total	15,100

United Nuclear announced plans to build a mill in the northeast Church Rock area in the early 1970s. In November 1975, ground was broken and the construction of this 3,000 TPD mill commenced; the target date for operations is the summer of 1977. United Nuclear and the Sohio-Reserve mills are the first to be constructed in New Mexico without benefit of government concentrate-purchase contracts.

During the latter part of 1976, Phillips Petroleum announced plans for a mill on its Nose Rock property and the Anaconda Company announced plans to enlarge its plant to a capacity of 6,000 TPD.

RESOURCES

Uranium resources consist of reserves and potential resources. Reserves are the firmest element of resources, comprising deposits that have been delineated by drilling or other direct sampling methods. Potential resources are the quantities of uranium estimated to be present in deposits that are incompletely defined or undiscovered. By declining order of

reliability, potential resources are divided into three categories: probable, possible and speculative.

The relationship of reserves to potential resources is illustrated below.

URANIUM RESOURCES				
DEFINED	INCOMPLETELY DEFINED OR UNDISCOVERED			
RESERVES	POTENTIAL RESOURCES			
	PROBABLE	POSSIBLE	SPECULATIVE	

Ore reserves are calculated from drill hole data and other engineering sources which are made available to the Grand Junction Office voluntarily by the uranium companies. Separate evaluations are made of the amounts of uranium that could be exploited at maximum forward costs of \$15 and \$30 per pound U_3O_8 , using established engineering, geologic and economic techniques and criteria.

Forward costs are those operating and capital costs yet to be incurred at the time an estimate is made. Profit and "sunk" costs, such as prior expenditures for property acquisition, exploration and mine development, are not included. Therefore, the forward costs are independent of the market price at which the estimated resources would be sold.

Potential resources, as used by ERDA, are estimates based on geological judgment of the undiscovered tons of U_3O_8 present in minable amounts in areas that are relatively unexplored in detail, but about which enough is known of the uranium geology to permit prediction of the nature and extent of favorable geologic environments. The geographic locations of potential deposits may be definable only within broad limits. Providing the subjective nature of potential is recognized and taken into account, potential plus reserves provide a more useful base for long-range predictions of domestic supply than do reserves alone.

The reliability of potential estimates varies with the classes. It is greatest in the probable class where there has been extensive exploration and where mines have been developed, thus defining ore habits, the nature and extent of the favorable host rocks, etc. The reliability is least in the speculative class where areas of favorability must be inferred solely from literature surveys, geological reconnaissance of formation outcrops and/or the examination of the logs and cuttings of wells drilled for petroleum or other purposes.

The uranium resources of the San Juan Basin as estimated by ERDA, as of January 1, 1977, are given in Table 2.

Nearly all of the reserves in both cost categories are in the Grants mineral belt, and most are associated with operating mines. The \$15 reserves represent 55 percent of the total domestic \$15 reserves, and the \$30 reserves represent 52 percent of the total \$30 reserves of the nation.

Probable potential resources in the San Juan Basin are estimated to occur in the uranium areas as extensions of known deposits, or as new deposits in trends or areas of mineralization that have been identified by exploration. Possible poten-

Table 2. Uranium resources of the San Juan Basin.

\$/lb. U_3O_8 Cost Category	Discovered Ore Reserves	Tons U_3O_8 Undiscovered (Potential)		
		Probable	Possible	Speculative
\$15	225,800	230,000	250,000	50,000
\$30*	356,400	395,000	455,000	65,000

*Includes \$15

tial resources are estimated to occur as new deposits within the Morrison Formation in areas of the basin which are not yet completely explored. Subsurface data, largely from oil and gas wells (Sears and others, 1972) have been used to determine the extent of the favorable ground. Speculative potential resources are restricted to Upper Cretaceous and Tertiary rocks which have not been productive, yet contain uranium occurrences and favorable geology for larger deposits.

Potential estimates are revised as new information becomes available. Recent increases in both the probable and possible classes are the result of new exploration which increased the size of the areas considered favorable. Speculative potential estimates are currently under review and will probably be decreased due to unfavorable exploration results. The extensive exploration currently underway within the basin is expected to convert a large population of the potential resources into reserves in the foreseeable future.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of Harlen K. Holen of the Albuquerque field office for his contribution of the potential resource estimates, and the help of Bette Learned for compiling the statistics.

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REFERENCE #50

NAVAJO SUPERFUND OFFICE
NANABAH VANDEVER
ABANDONED URANIUM MINE

T. MORRIS JUNE '90

CONTACT REPORT

Meeting: (X)

Telephone: ()

Other: ()

CONTACT LOCATION: Bureau of Indian Affairs,

ADDRESS: Window Rock, AZ 86515

PERSON CONTACTED

and TITLE: Ervin Mariano, BIA minerals

PHONE: 602-871-6405

FROM (Contacting

party): Tom Morris, Environmental Specialist, Navajo Superfund Office

DATE: 6/26/90

SUBJECT: Subsurface rights on Indian Allotment Lands, and the
connection between allotment lands and the Navajo Nation

INFO.

REPOSITORY:

CONTACT SUMMARY REPORT:

The allottee owns the subsurface rights and is entitled to royalties.
The allottee, if a registered voter with the Navajo Nation, is
entitled to tribal services such as water, housing, electricity,
roads, etc. through their local chapter with the approval of the
area BIA agent.